GENESIS, CLASSIFICATION AND POTENTIAL PRODUCTIVITY OF SELECTED WETLAND SOILS IN THE SAVANNA ECOSYSTEM OF NIGERIA.

GBADE OYEWUMI OYEDIRAN
(B. Agric. (Soil Science), M.Phil (Soil Sc.) (Ife))

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY

DEPARTMENT OF SOIL SCIENCE,
OBAFEMI AWOLOWO UNIVERSITY,
ILE-IFE, NIGERIA.

1990

This thesis is dedicated to my loving wife, Adenike, and my children, Tosin and Mayowa.

ACKNOWLEDGEMENT

To realise a piece of work of the kind presented in this thesis a great number of persons must have given a hand in its execution. Foremost, it is with great delight that I acknowledge my indebtedness to my project supervisor, Dr. T. A. Okusami, through whom I acquired tremendous research experience which saw me through this work. His open-door policy coupled with high level of understanding, interest and guidance contributed immensely to the success of this work. I will like to acknowledge the fact that he travelled with me to the sampling sites despite his tight schedule. His valuable suggestions and constructive remarks are greatly appreciated. I wish to express my sincere gratitude to: Dr. T. Wakatsuki, Faculty of Agriculture, Shimane University, Matsue 690, Japan and Dr. A. Fagbami, Department of Agronomy, University of Ibadan, Ibadan for their assistance during the course of my field work; and Dr. M.C. Palada, IITA, Ibadan for providing some information on swamp rice production.

I am particularly grateful to the Government of Japan for providing financial support for this study through the Japan International Co-operation Agency (JICA)/International Institute of Tropical Agriculture (IITA) collaborative project, under IITA's Rice-Based Cropping Systems (RBCS) unit of Resource and Crop Management Program. I am also grateful to the authority of Obafemi Awolowo University, Ile-Ife for giving me financial assistance in form of Postgraduate Fellowship award. Moreover, I wish to recognise the contributions of Dr. B.D. Ako, Mrs. A. Dabiri, Mr. A. Oyedipe, Mr. T. Williams, Mr. A. Amusan, Mr. T.L. Oyediran, Mrs. S.A. Olagunju, Mr. and Mrs. A.V. Akintude.

My warm appreciation goes to my parents, Chief David Oyediran and Mrs. Deborah Oyediran, my sister, Mrs. V.B. Ajayi and to fellow graduate students of the Department of Soil Science who through their useful suggestions and moral support contributed to the success of this work. My gratitude also goes to Mr. 'Bosun Adeleke who did a marvellous work of typing and producing the thesis. Finally, I am very grateful to the almighty God, who in his infinite mercy granted me the patience and will power to make this work a success.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Wetlands are extensively used for lowland rice (Oryza sativa L.) cultivation in Nigeria. Selected wetland soils in the savanna ecosystem (between latitudes 7°45' and 12°50'N) of Nigeria were studied to evaluate their physical, chemical and mineralogical properties for proper understanding of their genesis and for placements in International and National soil classification systems. Potential productivity indices of the soils were developed for lowland rice (Oryza sativa L.) cultivation. The possibility of dry-season cultivation of sorghum (Sorghum bicolor (L) Moench) are discussed. Transects were selected to represent different soils formed in different parent materials and agroecosystems. A total of twenty-three (23) soil profile pits located on different physiographic positions were sampled and studied. They consist of the following: Makurdi transect with five profile pits (pedons MD1 - MD5); Gadza transect has six (pedons GZ1 - GZ6) while Dwam transect has three (pedons

DM1 - DM3). Six profile pits were located in Argungu transect (pedons AR1 - AR6) whereas Lumda transect has three (pedons LD1 - LD3). All pedons of Gadza transect and those of levees (pedons MD1, AR1 and AR4) and pedon LD3 were sandy, whereas soils of backswamps (pedons MD2 to MD4, DM1, AR2, AR3 and AR5) and those formed in shale-dominated parent materials (pedons DM2, LD1 and LD2) were clayey.

Soils of Makurdi and Gadza transects were generally acidic (pH 4.8 - 6.4), whereas those of the other transects were acid in reaction or neutral (pedons DM2 and LD1) to alkaline (pH 8.0, pedon AR5). The effective cation exchange capacity (ECEC) of soils of Makurdi, Gadza, and Argungu (except pedon AR3) transects which are formed in mainly sandstone - derived parent materials ranges between 1.09 and 13.04 cmol(+)kg^{-1} of soil. Pedons DM2, LD1, LD2 and LD3, however, had relatively high ECEC values of between 6.83 and 35.20 cmol(+)kg^{-1} of soil. The organic carbon content of the soils ranges between 0.01 and 0.76%

whereas total nitrogen ranges between 0.01 and 0.08%.

Quartz dominated both sand and silt mineralogy. The clay mineralogy of the soils was mostly kaolinitic except pedons DM2, LD1 and LD2 which were smectitic. Eluvial/illuvial transportation processes have contributed to the formation of argillic horizons in pedons GZ5, GZ6, DM3, AR5 and AR6. The only noticeable active pedogenic process in pedons DM2, LD1 and LD2 was soil displacement, as evident by the presence of slickensides. The wetland soils are mainly Inceptisols and Entisols (FAO: Gleysols and Fluvisols) whereas the adjoining upland soils are Alfisols (pedons MD5, AR5, AR6 and DM3) and Ultisols (pedons GZ5 and GZ6) which will classify as Lixisols and Acrisols in FAO system. Pedons DM2, LD1 and LD2, however, are Vertisols.

The mean potential productivity indices (P) for lowland rice in Makurdi, Gadza, Dwam, Argungu and Lumda transects are 0.45, 0.36, 0.30, 0.18 and 0.09, respectively. The main constraints are low soil fertility, water availability and high salinity. Only pedons MD2, MD3, MD4, DM1, AR2, AR3 and AR5, because of their fine texture, may be suitable for dry-season cultivation of sorghum.

CHAPTER ONE

1.0 INTRODUCTION

The savanna ecosystem occupies about eighty percent of Nigeria land mass. Ecological interpretation of savannas shows a wide variety of physiognomic types under different climatic, topographic, soil conditions, and degrees of human interference (Sarmiento and Monasterio, 1975). Savanna has been defined by Sanford and Isichei (1986) as 'seasonal tropical vegetation in which there is a closed or nearly closed cover of grasses at least 80cm high with flat, usually cauline, leaves; usually burnt annually; trees and shrubs at various densities most often present'. It is apparent that soil characteristics such as drainage, soil depth, structure and texture, water retention capacity, and fertility strongly influence vegetation on a local scale. In dry tropical forests, savannas develop first in areas of poor and/or shallow soils, but with extreme drought stress they may develop even over fertile soils. Thus savannas are seen to develop in response to a dynamic interplay of soil and climate.

Wetlands usually occur in lowlands or depressions, hence materials eroded and transported from the surrounding uplands tend to accumulate there. This has led to the hypothesis that much of the sediment and nutrient load leaving the upland were being trapped in the wetland. Wetlands are very productive (Moore and Bellamy, 1974; Richardson, 1979), and in the savanna ecosystem of Nigeria, they have become centres for farming populations, as evident in the 'Fadamas'. The boundary between wetland and dryland fluctuates from year to year, depending on variations in rainfall. Van Diepen (1985) defined wetland as land subject to excessive wetness to the extent that the wet conditions influence the possible land uses. Wetlands can be categorized as coastal plains, including estuaries and deltas; river floodplains, comprising recent alluvial deposits bordering rivers; inland basins, consisting extensive drainage depressions; and inland valleys, which occur frequently in the undulating landscape.

Wetland soils are hydromorphic soils whose development and properties are strongly influenced by temporary or permanent saturation in the upper part of the pedon. Two types of wetland soils (surface-water gley and groundwater gley) are common. The wet condition of the soil may either be due to the surface water from precipitation that cannot be removed as fast as it arrives or because the groundwater is seasonally or permanently at or above the soil surface. Surface water is retained on level ground or in depressions because of a slow hydraulic conductivity of the soil (Brinkman and Blokhuis, 1986). Another form of surface-water gley soil is stagnogley which has an extremely low hydraulic conductivity in the substratum so that percolation is virtually absent. Therefore water saturation occurs periodically only in the epipedon. In groundwater gley soils, the lower soil horizons are permanently under the groundwater table and they are usually gray or greenish gray because of the reduced conditions. The upper soil horizons may be gray mottled with brownish or black, mixed iron-manganese oxides.

Wetland soils are very variable. They range from soft, massive or single grained in permanently submerged conditions, to firm, consolidated, with a blocky or prismatic structure in seasonally dry environments. Their texture ranges from clay to sand. Swamp rice owes its occurrence and productivity to soil, moisture and climatic characteristics. Though total effective rainfall is important for rice cultivation, rainfall distribution is even more important. Rice requires an annual precipitation of about 1,000mm with a monthly rainfall of about 200mm during the growth cycle (Brown, 1969; De Datta, 1975).

The crop also requires high temperatures (ranging from 20°C to 30°C) and long periods of sunshine during growth.

There has been a general decline in world rice production (I.R.R.I, 1988) which has resulted in high retail prices for the available rice. Slightly increasing production levels due to the recent ban on rice importation in Nigeria has still not met local consumption, and recent price trends have not shown any improvement. Ayotade and Okereke (1984) estimated that the wetlands currently under rice cultivation (about 300,000 hectares) account for about 75 percent of the national production. The estimated production of paddy in Nigeria rose from 350,000 metric tons in 1970 to close to 1.5 million tons in 1983 (Ayotade and Fagade, 1986). As of now, there are still large hectarages of wetlands unused for cultivation.

Most systems of soil classification distinguish classes of hydromorphic soils, i.e. soils with defined signs of periodically or permanently reduced conditions. Hydromorphic soils are distinguished from soils with free internal drainage at the suborder level in Soil Taxonomy. With the exception of oxidation-reduction processes, the genesis of soils with aquic moisture regimes has not received the same attention as that of better drained analogues (Bouma, 1983). Therefore, many of the properties and processes in wetland soils still need to be verified. The study of the genesis and classification of wetland soils should help to facilitate their management for good agricultural uses.

1.1 Objectives

The objectives of this study were:

(a) to evaluate the physical, chemical and mineralogical properties of some wetland soils in the savanna ecosystem of Nigeria for proper understanding of their genesis;

(b) to classify them using the above characteristics; and

(c) to evaluate the productivity potentials of the soils for lowland rice and other suitable crops.

CHAPTER TWO

2.0 LITERATURE REVIEW

Soil is a collection of dynamic, natural, three dimensional bodies which results from effect of climate and the activities of living organism upon parent material as conditioned by the local relief, all acting over a period of time.

2.1 Factors of soil formation.

2.1.1 Parent material: Except for the lithomorphic Vertisols, all other types of hydromorphic soils are formed in sediments that are usually found in the lowest part of the landscape. These sediments are either of colluvial or alluvial origin.

The parent materials underlying depressions and basins in Nigeria can be related to the surrounding uplands because of the geological stability of the African continent. Probably most of the sedimentary deposits or hydromorphic soil parent materials in the savanna region of Nigeria have been formed from pre-weathered, multicycled soil materials that were derived from the uplands. The origin of most of the hydromorphic soils in northern Nigeria has been influenced by the basement complex (intermediate to acid crystalline rocks) and by various sedimentary rocks, which are mostly arenaceous (Moormann and van Breemen, 1978). If this is the case, one may then expect sediments in the savanna ecosystem of Nigeria to be rich in such primary minerals as quartz, feldspars, muscovite, oxides of Fe, zircon and some other heavier minerals. The clay mineralogy is predominantly kaolinite, quartz, iron oxide minerals (goethite, hematite or limonite), hydrous mica and muscovite (Ojanuga, 1979; Okusami et al., 1987). In Vertisols and soils with vertic properties where parent materials are of lithomorphic type, the 2:1 clay minerals are residual from basic rock. Where the topographic influence is prominent, parent materials are usually also related to the primary minerals and to the 2:1 clay mineral group (Purnell, 1979). Generally, the parent materials of most hydromorphic soils in depression and closed basins will reflect the lithology of the surrounding drainage basins.

2.1.2 <u>Climate:</u> Climate influences soil formation by control of the chemical and physical reactions taking place in the soil and also by its control of the organic factor and to some extent of the factors of relief and time through erosion and deposition of soil materials. In areas of high rainfall, the climate might have been a 'levelling' factor towards evolving sediments of similar mineralogy. Available weatherable minerals appear to vary by agroclimatic regions, particularly as a result of rainfall distribution and amount (Jones and Wild, 1975). Climate influences rate of leaching, weathering and decay of organic matter. Leaching of bases and podzolization process will progress more quickly with heavy rainfall than light rainfall. Weathering of rock minerals and decay of organic matter is quicker in a hot, moist climate than cool, dry one (Buol *et al.* 1980).

Several soil properties have been shown to be temperature dependent. Soil colours tend to become less gray and more reddish with increasing temperature. Nitrogen and organic matter contents decrease as the temperature increases. High temperatures and precipitation normally favour hydrolytic type of weathering. Righi and Lorphelin (1986) reported that hydrolysis might occur with acidocomplexolysis at the same time or one after the other during the year. The following weathering zones have been identified in the world based on general climate (Buol *et al.* 1980):

(a) Podzolization occurs in cold humid climate, characterized by strong complexolysis (i.e complete removal of Al, Fe and other cations, deposited at B horizon).

(b) Braunification occurs in temperate climate; dominant weathering process is slow acid hydrolysis that weathers the parent material to shallow depth (about 1m);

(c) Intermediate fersiallization occurs in seasonally contrasted subtropical climate - found in the meditteranean region with hot dry summer. There is rapid mineralization and the soils are rich in SiO_2, Ca^{2+}, Mg^{2+} and 2:1 clay minerals; and

(d) In hot humid climate (describing equatorial environment), ferallitization occurs. Here there is neutral hydrolysis, weathering is total and results in complete release of elements. Kaolinite is the commonest type of clay formed.

Ojanuga (1979) claimed that the warm soil temperature conditions prevailing in the guinea savanna region of Nigeria are believed to have the capability of causing marked dissociation of soil water. This will cause a build-up of hydrogen ions thus leading to the hydrolytic or H-weathering of silicates to kaolinite.

2.1.3 <u>Vegetation:</u> Vegetation cover has significant effects on soil temperature. Murtha and Williams (1986) reported that this effect in both humid and semi-arid tropics of Australia was sufficient to cause a shift from iso to non-iso regimes; for a change from vegetated to bare surfaces. The influence of plant species and their distribution become very important during the dry season in the seasonally wet/dry cycle soils due to evapotranspiration. The influence of water and soil type on native vegetation of a habitat is more important than the influence of vegetation on soil development of hydromorphic soils. Cole (1973) attributed the variation in species diversity observed in a seasonally flooded tropcial swamp to the duration of the saturated environment with species diversity increasing from permanently flooded environment to well-drained sites.

He stated further that the single species of grass-herb dominates areas with longer duration of flood. Phillips (1959) used soil moisture as a classification criterion and so derived classes of vegetation such as mangrove woodland, freshwater swamp forest, periodically inundated forest, riverine and floodplain.

2.1.4 Time: Estimates of relative soil age have been based on the degree of horizon differentiation and the thickness, clay content, solum thickness, and other morphological or chemical properties that are believed to vary systematically with time. The morphology of a soil reflects the alteration of that soil's parent material by soil forming processes. In Oregon, Balster and Parsons (1968), and Parsons and Herriman (1975) have observed argillic horizons developed in recent alluvium aged between 2,350 and over 5,250 years. Gile and Grossman (1968) concluded that in the arid regions of the southwestern United States, argillic horizons appear to require more than

5000 years to form. In Iowa, Fenton et al. (1974) reported that alluvial soils of approximately 6,600 years old had argillic horizons while those of 2000 years in age did not. However, Balster and Parsons (1968) noted that cambic horizons are found in recent alluvial soils with an age of approximately 550 years. Also in Pennsylvania, Cunningham et. al. (1971) have observed cambic horizon development and minimal clay illuviation in recent alluvial soils with an age of approximately 450 years.
Bilzi and Ciolkosz (1977) concluded that morphological properties are effective in distinguishing chronologic age differences in alluvial soils which differ by approximately 1,500 years in age, but are not effective when the age differences are only a few hundred years. They also indicated that cambic horizons can develop in less than 200 years and can still be present after 2000 years of soil formation.

Arduino et al. (1986) used iron oxides and clay minerals within profiles as indicators of soil age. They found that the ratios ($Fe_{(d)}/Fe_{(t)}$ and $Fe_{(d)}-Fe_{(o)}/$

$Fe_{(t)}$ were closely related to the ages of the terraces. Clay minerals were also related to terraces ages, with 2:1 clay minerals dominant in the profiles on the youngest and mixed-layer minerals and kaolinite more abundant in profiles on the older terraces. Generally, the forms of iron become progressively 'less active' as soils become older (Arduino et al., 1986).

2.1.5 Topography: The concept of catena describes the association between particular slope forms and soil sequences. Miline (1935) originally defined a catena as 'a grouping of soils which while they fall apart in a natural system of classification on account of fundamental and morphological differences, are yet linked in their occurrence by conditions of topography and are repeated in the same relationhsips to each other wherever the same donditicns are met with'. The differences between the soils of a catena are generally related to differences in their position and their drainage characteristics. These differences are brought about by drainage conditions, differential transport of eroded material and leaching, translocation and redeposition of mobile chemical constituents (Milne, 1936). The differences in drainage are responsible for the gradual colour changes that are frequently seen in toposequences. Upland, well-drained soils are usually reddish-brown, showing the presence of non-hydrated iron oxide in the soil. On the middle and lower parts of the slope, the soils remain moist longer and dry out less frequently and less completely (Gerrard, 1981); this leads to an increasing degree of hydration of the iron. The red colour then changes to a brown or yellow; the hydrated iron oxides are mainly goethite and limonite. On the lowest slopes, where the drainage can be very poor and where part or all of the soil profile is waterlogged, reduction of Fe and other soil compounds take place. These waterlogged soils are usually bluish-gray, greenish-gray or neutral gray in colour. At the break of slope where the water table fluctuates, mottling is likely to be pronounced.

Many of the characteristics of floodplain soils are related to the distinctive nature of the landform. Each landform type is associated with a slightly different type of sediment and therefore, the basic soil materials differ considerably. Levees are generally formed from the coarse materials carried by flood water. When river flows in excess of the bankfull stage, the water overflows the levees, becomes less turbulent and the finer silts and clays accumulate in the backswamp areas. The rate of sediment accumulation depends on the size and quantity of sediment and the frequency of flooding. Coarse material settles rapidly but finer clays take longer time.

2.2 Soil development evaluation.

Several approaches have been used to study soil development. Various workers have postulated the use of different weathering indices to assess the stage of soil development. For example, Brewer and Walker (1969), were of the opinion that increasing soil age is reflected in progressive finer texture, while Campbell (1971) argued that stronger structure is a better index. Reness of B horizons has been correlated with free iron content (Alexander, 1974; Birkeland, 1974; Ojanuga, 1977; Buol et al. 1980) and has also been used to estimate relative soil age because ferric iron is very insoluble and accumulates in oxidised weathering environments with time. Bigham et al. (1978) found that spectral hue of Ultisols in North Carolina was related to iron content and to the proportion of hematite to goethite, and that hematite increased relative to goethite, with increase in free iron content.

Silica-sesquioxide ratios defined as the molar ratios of SiO_2 (silica) to $Al_2O_3 + Fe_2O_3$ (sesquioxide or R_2O_3), and SiO_2 to Al_2O_3 (alumina), were believed to give a method that can be used for mineral identification and for estimating the degree of weathering and relative translocation of soil constituents in the pedon (Jenny, 1941; Birkeland, 1974). Kaolinite clay minerals have been reported to exhibit a SiO_2/R_2O_3 ratio in the range of 1 to 2, with a corresponding SiO_2/Al_2O_3 ratio of 2 to 3. On the other hand, smectite - montmorillonite displayed higher ratios, with SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios ranging from 2 to 3 and 3 to 4, respectively (Grim, 1968; Wakatsuki and Wielemaker, 1985). Decreasing SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios with depth in the pedon have been found to be indicative of movement of Fe and Al, and/or clay migration, whereas increasing ratios have been interpreted as movement of Si to deeper depth in the pedon. The silica-sesquioxide ratios of soil clays were also reported to beoome narrower with increased degree of weathering and/or increased humidity (Mohr _et al;_ 1972). Sianu and Pundeer (1978) argued in favour of the use of CaO/ZrO_2 ratio for establishing the weathering stage in soils developed in alluvium, whereas silt/(silt + clay), Ca^{2+}/Mg^{2+} and Fe_2O_3/Al_2O_3 ratios

(Ogunwale and Ashaye, 1975) were used in assessing the degree of weathering of sandstone-derived soils of southwestern Nigeria.

Analysis of sand-size minerals has been used extensively in pedological investigations. In particular, minerals that are highly resistant towards mechanical and chemical weathering processes, for example zircon, monazite, quartz and tourmaline can serve to establish associations between source rocks and weathering stage. Sudom and St. Arnaud (1971) demonstrated the feasibility of using quartz and zirconium oxide (ZrO_2) content of soil horizons and size fractions to establish the uniformity in soil deposits with depth and to quantitatively evaluate changes. A more recent approach to evaluation of soil development was proposed by Santos et al. (1986). Termed 'pedogenic index', it is calculated by using the ratios of weight of K_2O/weight of quartz of A and C horizons. Ogunwale and Ashaye (1975) indicated the prominence of kaolinite, and interstratified clay minerals in the clay fraction as an evidence of advanced weathering.

According to Mckeague and Day (1966) approximate differentiation among the forms of Fe and Al in soils can be made by selective extraction methods. Both oxalate - and dithionite extractable Fe and Al values are useful in the studies of soil genesis and classification. The oxalate extraction dissolves much of the iron and Al from the amorphous materials but very little from crystalline oxides, whereas the dithionite extraction dissolves a large proportion of the crystalline Fe oxides as well as much of the amorphous materials. The oxalate values give an approximation of the degree of accumulation of amorphous products of recent weathering in the horizons of soils formed from materials varying widely in texture, colour, pH, organic matter and total iron oxides. Ashaye (1969) studied the relationships between clay content and Tamm's acid-oxalate extractable Fe and Al. He found that the relationships were not significant. However, he concluded that the amount and nature of the various forms of Fe and Al oxides and organic complexes may greatly influence the physical and chemical properties of the soils. The forms of sesquioxides likely to be most active in soils are the amorphous (mobile) forms. High $Fe_{(o)}/Fe_{(d)}$ ratios usually obtained in organic-rich horizons show relatively higher amounts of mobile Fe possibly as organo - Fe complexes (Mckeague _et al;_ 1971; Ojanuga, 1977).

Arduino _et al._ (1984) proposed that $Fe_{(o)}$ is the 'active' and $Fe_{(d)}$ minus $Fe_{(o)}$ the 'less active' forms of iron, the latter probably being goethite and hematite. Their findings suggest that changes in forms of iron continue as soils become older with more progressively going into 'less active' forms. The ratio of B horizon dithionite extractable Fe ($Fe_{(d)}$) to total Fe ($Fe_{(t)}$) ratios is more useful in assessing relative soil development than $Fe_{(d)}$ alone because the former is not dependent on Fe content of initial material (Rebertus and Buol, 1985). Ratios of $Fe_{(d)}/Fe_{(t)}$ should reflect the degree of alteration of Fe - bearing primary minerals and the degree of Fe - accumulation in illuvial horizons.

2.3 Properties of wetland soils.

2.3.1 Morphology:

Hydromorphism can be described as a process whereby the soil is under reduced conditions either due to the permanently high water table ('peraquic', 'gley', 'groundwater gley') in the soil profile or a temperary period of saturation ('aquic', 'pseudogley', 'surface water gley'). Gley soils exhibit permanent grey subsoil colours with or without mottled topsoil horizons depending on the availability of Fe oxides, while pseudogleys have seasonal grey colours and rusty brown ferric oxide colours along free surfaces of the root channels and ped faces (Schlichting, 1973).

The varying degree of hydromorphism in soils is reflected in the intensity of motttling, gleying, structural development and the degree of development of plough sole. Kanno (1978) summarised that eluviation, mottle formation, gleization, plough-sole formation, degradation, redistribution of exchangeable bases, accumulation (or decomposition) and alteration of organic matter and some other processes lead to profile differentiation of seasonally flooded soils. Many researchers have attempted to define quantitatively the soil moisture regimes that have produced certain hydromorphic soil features such as specific mottle colours and patterns. Van Wallenburg (1973) used the depth of the uppermost point in the soil profile that exhibits a mottled colour or a colour that was noticeably grayer than that of comparable horizons as a distinguishing feature in drainage. This involves the study and understanding of adjacent upland soils. Daniels *et al.* (1971) observed thick A horizons and fine-textured B horizons in soils with deep water tables, while shallow water tables were associated with thin A horizons, low-contrast mottling and presence of Bc horizons.

Pickering and Veneman (1984) in a study of a hydrosequence reported that lowest chroma colours were found in the very poorly drained soils where perennial conditions of saturation or near saturation exists up to the soil surface resulting in the strongest reducing environment; whereas matrix colours of highest chromas (6 or higher) occurred in the moderately well-drained soils where reducing and oxidising environment coexist within the profile at sometime during the growing season. Occurrence of mottling has been associated with depth to the water table (Guthrie and Hajek, 1979). Simonson and Boersma (1972) used mottling features to define drainage conditions. They correlated faint and distinct mottling with the presence of water-table and noted a consistent increase in the size and abundance of Fe and Mn concretions with poorer drainage conditions. In the intermediate drainage classes, the soil is often close to saturated as moisture tension approaches zero (Veneman et al., 1976).

It has been shown through physical experimentation by Vepraskas and Bouma (1976) that mottle patterns are the result of different moisture regimes. Simulated profiles of permanently unsaturated moisture regimes and of periodically unsaturated moisture regimes and of periodically prolonged saturated regimes, respectively, showed ped mangans and channel neoalbans, quasimagan types of mottles; that is, mottle patterns differing with regard to areas of occurrence and pattern of formation. Veneman <u>et al.</u> (1976) concluded that soil morphological features such as mottles or chromas of 2 are sufficient indicators of hydromorphism and also that the duration of soil saturation or water-table position can be inferred from the mottle patterns. Similarly, Coventry and Williams (1984) recently reported direct relationships between some soil morphological features (grey mottles, mottles with chromas of 2 or less, maximum content of clay, and base of the solum) and different soil hydrological regimes in some Alfisols.

However, Veldkamp (1979) found that in some cases, in sites around Ibadan in Nigeria, mottling could not be related to the length of the periods of water saturation.

Occurrences of concretionary horizons over mottled and/or pale gray horizons have been recognized to be the result of seasonal water-logging with mobilization of Fe eventually followed by its oxidation into a concretionary zone. Richardson and Hole (1979) noted two modes of Fe translocation in which Fe first tends to migrate in association with clay from surface horizons to those deeper in the profile and then redistribute within the peds of a horizon. Maximum Fe concretions occurred in somewhat poorly drained soils with alternating oxidising and reducing conditions, but fewer concretions were found in very poorly drained soils on similar landscapes and parent materials. Schwertmann and Fanning (1976) concluded that optimal concretion formation occurred in soils with rapid changes in aeration and concordant fluctuations of redox potential. When the diffusion of oxygen throughout the soil is limited by increasing moisture contents, the redox potential drops and compounds containing Fe and Mn become reduced (Gotoh and Patrick, 1974). Iron and Mn are mobilized by reduction and can contribute to the formation of mottles or concretions when the soil environment becomes more oxidized during subsequent drying cycles. Concretions may also be due to silica cementing soil particles together. They are presumably due to some of the mobile silica in the soil solution being precipitated as a cementing agent. Silica cementation occurs only when the clay is of the non-kaolinite type but not of the swelling beidellite or montmorillonite type (Kantor and Schwertmann, 1974).

2.3.2 Electrochemical properties of variable charge surfaces:

The electrochemical properties of soil, viz, the pH, zero point of charge (ZPC) and relative values of CEC and AEC (adsorption) are important in most pedological investigations. These properties have been attributed to the existence of the two major types of colloids (van Olphan, 1963):

(a) those with completely polarizable interface or constant surface chagge, and

(b) those with reversible interface or constant surface potential.

The former type of colloid is mainly associated with soils of the temperate region while the latter is dominant in the "humid tropical soils" (van Raij and Peech, 1972). The constant surface charge colloids are dominated by the 2:1 layer group minerals, where negative layer charge results from the interior of the structure. The constant surface potential (or variable charge) is very much transient and superficial, being mostly due to oxidic coatings of the layer silicates and charges arising from edges of fragmented silicate layers and amorphous material. Soil pH has a direct relationship with such properties as the zero point of charge, adsorption and ion exchange processes in the solid-solution interface of the soil's environment.

Zero point of charge (ZPC) is defined basically as the pH at which the net surface charge of soil materials is zero. Zero point of charge (ZPC) now assumes a significant dimension in the study of soils of humid tropical areas because it contributes to the understanding of other electrochemical properties. van Raij and Peech (1972) reported that the zero point of charge of soils reflects the overall mineralogical composition and organic matter content of the soils. They pointed out that soils with high sesquioxide content tend to have a higher ZPC at higher pH values, whereas layer silicates with permanent negative charge and organic matter will have a lower ZPC at higher pH values. This implies that a soil with predominantly 2:1 layers, i.e, the constant surface charge types may have a very low or non-existent ZPC (Parks, 1967) while a high ZPC will be a typical property of the 1:1 layer silicates and oxidic soils which is said to be a reflection of the intensity of weathering and sometimes age of the pedon. A relationship between the soils' ZPC and the difference in pH determined in both water and 1.0M KCl was established by van Raij and Peech (1972). If $pH_{KCl} > pH_{H_2O}$, the pH of the soil should be on the positive side of the ZPC, and the soil will have a net positive charge. But if the reverse occurs, i.e. $pH_{KCl} < pH_{H_2O}$, then the pH of the soil lies on the negative side of the ZPC and the soil will carry a net negative charge. A negative ΔpH ($pH_{KCl} - pH_{H_2O}$) has been said to indicate that the soils contain colloids of the constant charge type while positive ΔpH (i.e $pH_{KCl} > pH_{H_2O}$) would indicate constant potential colloids with net positive charge (Mekaru and Uehara, 1972). A negative Δ pH has also been implicated (Keng and Uehara, (1974) to mean the abundance of silicate clay minerals over oxides. The closer the pH of the soil gets to or approaches that of the ZPC, the more weathered is the profile (Stoops, 1980). On the other hand, in a pure oxide system the pH of the soil equals that of the ZPC. By definition, Ultisols and Oxisols are the only soil orders whose ZPC values may be approaching that of a pure oxide system, because of their relatively high sesquioxide contents.

2.3.3 Redox transformation.

The major electron donors in the soil system are the oxidizable organic compounds while oxygen is the major electron acceptor. Other electron acceptors in anaerobic natural soil systems include iron, manganese, sulphur, cobalt, nitrogen and copper compounds. It is the influence of the reaction products which result from the redox systems that mainly contribute to the soil formation processes unique to the hydromorphic soils.

When an aerated soil is waterlogged, oxygen and nitrate disappear in that order and the appearance of manganous ion (Mn^{2+}) in the soil solution and on the exchange sites immediately follows. Manganese plays an important role in the processes of soil formation in flooded and poorly drained soils. Insoluble, oxidized manganic compounds (Mn^{4+}) are reduced to the more soluble manganous (Mn^{2+}) form. An increase in Mn^{2+} in the soil solution and on the exchange complex if the pH is acid or slightly acid is one of the first measurable effects of reducing conditions. The concentration of soluble Mn^{2+} in the soil solution is highly dependent on both pH and redox potential (Patrick and Reedy, 1978) but at pH values below 5, pH alone controls solubility. Mitra and Mandal (1983) reported a highly significant negative relationship between exchangeable Mn and pH. They, however, observed a positive correlation of exchangeable Mn with clay content of the soils, and a strong positive correlation between reducible Mn content and period of water-logging of the soils. It has been noted that manganese exists in at least four different forms in waterlogged soils: (1) water soluble, (2) exchangeable, (3) easily reducible and (4) residual manganese or that remaining after extraction of the other three forms.

Patrick and Turner (1968) showed that the exchangeable and the easily reducible fractions accounted for most of the manganese in the waterlogged environment. The measurement of the easily reducible manganese (ERMn) should then indicate the capacity of a waterlogged soil to provide the soil with both exchangeable and water soluble manganous ions. Similar work with regards to iron distribution in a waterlogged soil was carried out by Gotoh and Patrick (1974).

The chemistry of seasonally flooded soils is dominated more by iron (Fe) than by any other redox element. Formation of horizons with Fe accumulation commonly found in seasonally flooded soils has been attributed to the redistribution of Fe and Mn in the flooded profiles. Pickering and Veneman (1984) in their study of moisture regimes and morphological characteristics in a hydrosequence reported significant translocation and leaching of iron in the poorly drained soils. Concretions in which Fe- and Mn-oxides are concentrated relative to the soil matrix typically occur in hydromorphic soils, particularly in soils with impeded internal drainage (pseudogleys). In these soils, Fe and Mn are mobilized by reduction and afterwards concentrated in various forms, among which mottles and concretions are the most frequent (Schwertmann and Fanning, 1976).

Patrick and Delaune (1972) as well as some other workers have reported that submerged soils usually have two zones in the epipedon of the profile, the oxidized zone and a lower reduced zone. These two zones have been characterised by various workers with redox potential values and/or inorganic constituents. The upper oxidized zone is dominated by ferric iron, manganic manganese, nitrate nitrogen, and sulphide. Patrick and Delaune (1972) showed that the profile distribution of the redox potential was almost identical to the profile distribution of ferric-ferrous iron distribution and that "the surface oxidized layer probably serves as an effective sink for the reduced forms of manganese, iron and sulphur since manganous, ferrous, and sulphide ions diffusing upward to this zone would be oxidized to insoluble manganic, ferric compounds (precipitated Fe^{3+}) and to elemental sulphur".

2.3.4 Ferrolysis:

Ferrolysis is an important soil-forming factor in hydromorphic soils. Brinkman (1970) hypothesized on ferrolysis as a hydromorphic soil-forming process and that the process dominates pedogenesis under some unique soil-water relationships. According to Brinkman, 'the term ferrolysis is derived from ferro(us) and lysis, and has been coined as a short term for disintegration of solution in water by a process based upon the alternate reduction and oxidation of iron'. During the process of ferrolysis, reduction of ferric oxides to soluble Fe^{2+} occurs in the wet season, the Fe^{2+} displaces and mobilizes exchangeable bases which (in addition to the soluble Fe^{2+}) are partially leached. In the alternating dry season, exchangeable Fe^{2+} is oxidized to form ferric and exchangeable hydrogen ions. This causes partial decomposition of the clay and the release of aluminium and silica. Partial neutralization of exchangeable Al along with the reduction of ferric oxide in the wet season produces relatively stable ferrous - aluminium hydroxide interlayers in 2:1 clays, leading to further reduction of the cation exchange capacity. Buol *et al.* (1980) stressed the significance of the alternation between strong reducing and oxidising conditions in silicate destruction of poorly drained soils with particular emphasis on those soils of the coastal lowlands.

2.3.5 Gleization:

Gleization can be considered to be different from ferrolysis in terms of the duration of the reducing influence (water saturation). Buol *et al.* (1980) defined gleization as 'the reduction of iron udder anaerobic waterlogged soil conditions, with the production of bluish to greenish gray matrix colours, with or without yellowish brown, brown and black mottles, and ferric and manganiferrous concretions'. Brinkman's concept indicated that ferrolysis will dominate soil formation processes during the alternating dry and wet cycles while gleization will dominate that of soils under almost permanent water saturation.

2.3.6 Soil mineralogy:

The chemical status of seasonally flooded soils is generally influenced by the clay mineralogy, which in turn reflects the parent materials and degree of hydromorphism. Parent rock (lithology) has a direct effect on clay mineral genesis (Ojanuga, 1979) as it controls to a large extent, the silica, alumina, and base potentials in the weathering environment. The control exerted by climate and topography tends to be indirect as both influence or modify the composition of the soil solution in the weathering environment. Advanced stage of weathering leads to the formation of kaolinite, indicating that the soil is in the stage of intermediate desilication (Jackson, 1965) or kaolinization (Pedro et al., 1969). The formation of smectite in poorly drained environment is often promoted by the incorporation into the soil solution of silica, alumina, and bases leached from the higher topographical sites (Gallez et al., 1976; Ojanuga, 1979).

The influence of hydromorphism on clay mineralogy of soils was demonstrated by Coventry et al. (1983). They noted that profile saturation for relatively short periods of time (few months) resulted in the formation of goethite, characteristic of the yellow earths and of the ferruginous gravel of the gray earths. Saturation for lengthy periods led to the loss of iron from the soil, which has then assumed the gray colour of the minerals (quartz and kaolinite) comprising the matrix. Brinkman (1978) observed the transformation of smectite and/or vermiculite into soil chlorite (chlorotization) particularly in the upper horizons of seasonally flooded soils. Kyuma (1978), however, concluded that the mineralogy of hydromorphic soils is almost the same as that of their parent materials since they are mostly either Entisols or Inceptisols, which have undergone little soil formation.

2.3.7 Changes in soil mineralogy induced by rice cultivation.

The primary mineral composition of hydromorphic soils would generally seldom show a noticeable change as induced by rice cultivation during a few hundred years, except for biotite which has been found to weather rapidly in seasonally flooded plough layers of rice soils (Kawaguchi and Kyuma, 1977). No significant difference was detected in the clay mineral composition among the hydromorphic soils studied by Kyuma (1978) regardless of the length of time rice had been in cultivation on the land, although Kawaguchi *et al.* (1957) had earlier reported that soils cultivated for rice for more than 100 years contained slightly less amounts of ferromagnesian minerals, such as hornblende and augite, than 'younger rice soils'. In their study of changes in clay mineralogy in a chronosequence of paddy soils in Japan, Wakatsuki *et al.* (1984) reported that prolonged paddy cultivation (150 and 265 years) brought about some modification in the clay mineralogy of Ap horizons, whereas the mineralogical changes were not evident in the profiles less than 75 years of age. The results obtained by Wakatsuki *et al.* (1984) indicated that the clay mineralogical changes induced by paddy cultivation were characterized by changes in smectite to chlorite. The interstratification and partial chloritization of smectite caused the CEC of the clay fractions of Ap horizon to decrease slightly.

2.4 Soil classification.

Poorly drained and swampy soils are usually situated in low topographical sites. Some soils, on the other hand, show a tendency to water-logging even in high topographical sites, well above the regional water table (Smyth and Montgomery, 1962). These soils have horizons of impervious clay at high levels in the profile, which prevent the free movement of water. Moss (1957) in classifying the soils found over sedimentary rocks in western Nigeria grouped the soils into drainage classes.

Most systems of soil classification distinguish classes of hydromorphic soils, that is, soils with defined signs of permanently or periodically reduced conditions. D'Hoore (1968) classified hydromorphic soils into mineral hydromorphic soils and organic hydromorphic soils. He defined mineral hydromorphic soils as: soils, other than Vertisols and similar soils, whose development and characteristics (presence of gley and/or pseudo-gley in at least one of the horizons) are influence by permanent or seasonal water-logging. According to Soil Taxonomy (Soil Survey Staff, 1975), hydromorphic soil has a moisture regime that is saturated most of the year whether this moisture regime affects the whole profile or just the solum or part thereof. Soil Taxonomy further defines that a soil or horizon is saturated with water when water stands in an unlined borehole close enough to the soil surface or the top of the horizon so that the capillary fringe (the zone just above the water table) reaches the surface or the top of the horizon in question.

In soil Taxonomy, soils with an aquic moisture regime and specified morphologic characteristics of wetness are distinguished at the suborder level. The aquic (L. aqua, water) moisture regime implies a reducing condition that is virtually free of oxygen. In situations where groundwater is always at or very close to the surface (as in inland swamps and mangrove swamps), the moisture regime is called 'peraquic'. The soils in the aquic sub-orders e.g. Aquents, Aqualfs, Aquepts - are gray or greenish - gray or bluish-gray (caused by continuously reduced conditions) or are mottled with contrasting colours caused by alternating reduced and oxidized conditions. Three orders - the Aridisols, Histosols, and Vertisols do not have aquic suborders. Essentially, all Aridisols are dryland soils and virtually all Histosols are wetland soils;

Histosols are subdivided by the degree of decomposition of the organic matter. Water saturation in Vertisols is always a surface feature (Blokhuis, 1982). In flooded Vertisols, only the surface horizon and the parts of deeper horizons adjoining cracks, particularly near the bottom of cracks, are water saturated for part of the year. There are also other cracking clay soils that have a very irregular boundary between water - saturated and dry or moist parts of the soil (Bouma et al., 1980). The Soil Sufvey Staff (1975) taxonomic units applicable to the soils in Nigeria are the Aquents, Aquepts, Aquolls, Aqualfs, Aquoxs, and Uderts (Andriesse, 1986). Aquic sub-groups have been defined in the Chromoxererts and the Chromuderts. These subgroups have distinct or prominent mottles in the upper 0.5m of the soil.

Moormann and van de Watering (1985) suggested that the definition of aquic moisture regime be broadened in a way as to include all soils subject to prolonged wetness and reduction in horizon less than, for example, one metre from the surface. The aquic moisture regime, thus redefined, could have one of the following forms:

Orthaquic:	true groundwater gleysoils (the aquic moisture regime as defined in Soil Taxonomy);
Peraquic:	as defined in Soil Taxonomy;
Endoaquic:	wetness and reduction by groundwater only in the lower horizons (criterion for aquic subgroups);
Epiaquic:	wetness and reduction only in surface horizons (the definition differs from that of epiaquic subgroups in Soil Taxonomy);
Anthraquic:	as epiaquic, but resulting from artificial ponding in wetland fields.

There are soils in which wetness has not led to reducing conditions (Moormann and van de Watering, 1985). Groundwater may contain considerable dissolved oxygen. For example, in the tropical areas with moderate relief and lateral water flow in the soil, the morphologic characteristics of the soil may not reflect the wetness. Also the lack of reducing microorganisms in some saline waterlogged desert soils precents the development of reducing conditions, and, in others, the lack of (readily decomposable) organic matter, in combination with high levels of $CaCO_3$, inhibits reduction. Moormann and van de Watering (1985) suggested that a special provision be made in Soil Taxonomy for soils that have an aquic (orthaquic or epiaquic) moisture regime in the wet season, but an ustic moisture regime in the dry season (part of the subsoil should be dry for at least 3 months), tentatively labelled as Ustaquic regime.

The dithionite-extractable Fe ($Fe_{(d)}$) tends to accumulate in the lower part of the zone where the water table fluctates. Consequently, some gleyed soil horizons contain high amounts of $Fe_{(d)}$. This is the reason that the Canadian system of Soil Classification (Canadian Soil Survey Committee, 1978) has Fera Gleysol and Fera Levic Gleysol classes to accomodate soils that have high $Fe_{(d)}$ due to water table fluctuations. Soils on wetlands, classified according to the legend of the soil map of the world (FAO-Unesco, 1988) include dystric Gleysols, Fluvisols, and Histosols (poorly drained soils of the freshwater swamps), gleyic Solonchaks (poorly drained saline soils), Arenosols and sandy Regosols, that is, coarse soils of sand bars and dunes (Andriesse, 1986).

2.5.1 Potential for rice production.

Rice culture can be classified into the following classes based on soil-water-rice interaction (IRAT, 1970):

(1) Upland rice: no soil water table high enough to provide the plant with its water requirement. Rainfall is the only source of water and its retention will be a function of the soils' texture.

(2) Lowland rice: when the water table is sufficiently high as to provide the plant with its water requirement. This include:

- swamp rice or rainfed paddy rice; when there is free water on the soil surface;
- deep-water rice; when water depth on the soils' surface is between 0.5m and 1.0m and
- floating rice; when free water is more than about 1m deep on the soils' surface.

(3) Irrigated rice land is land on which the water table can be controlled by inlet/outlet mechanisms and can be applicable to any of the above conditions.

2.5.2 Soil water management.

Water conservation is a priority in lowland (wetland, rainfed) rice cultivation. Evidence has been shown that rice yield is much higher in saturated and flooded soils than in aerobic soils (IRRI, 1963). Many studies have been carried out on the effects of water on rice yield in tropical Asia. The consensus is that irregular water availability consistently causes low average rice yield on farmers' fields when compared to those obtained in experimental trials under lowland rainfed conditions (De Datta *et al.*, 1973). Veldkamp (1979) found out on some Nigerian toposequences that yield responses of rice are highly related to the groundwater class. Generally, water management seems to be the most important factor in rice production.

2.6 Soil productivity.

Productivity capacity or expected yields are useful in predicting the suitability of any soil for agricultural use. Productivity indices have been developed in various parts of the world. Examples are those developed by Clarke (1951) in Britain; Storie (1954) in California, U.S.A.; Durand (1965) in France; and F.A.O. (1965) in Nigeria. Soil productivity ratings can be expressed either qualitatively or quantitatively. Qualitative ratings may be as narrative statements of soil suitability for particular crops, or they may group soils subjectively into a small number of classes or grades of agricultural suitability. Quantitative expression of soil productivity may be done inductively or deductively. Inductive productivity ratings are derived solely from the inferred effects of various soil and land properties on yield potential of a soil. Crop yield data are not used directly in the calculation of productivity indices. Deductive productivity ratings, on the other hand, are based entirely on records of crop yields obtained from different soils. In deductive productivity ratings, productivity is expressed in absolute rather than relative terms. For most applications, absolute values of expected yields are less important than relative comparisons of yield potentials among soils. Indices of relative yield are much less subject to temporal variability due to management, technology, or weather.

Sys and Frankart (1971) developed a multiplication index for soils under natural vegetation or subsistence agriculture in the humid tropics. The F.A.O. (1965) index in Nigeria is another example of the multiplication method based on soil depth, texture and structure, base saturation, salinity, organic matter, nature of clay, mineral reserve, drainage and moisture content.

Potential productivity is the maximum level of productivity that can be obtained under high level of soil management. In developing the potential productivity index, the permanent and temporary limitations to be considered are land properties which cannot be changed by normal agronomic practices. These include soil texture and surface stoniness, nature of clay minerals, mineral reserve, soil depth and salinity.

2.6.1 Soil texture

The significance of soil texture is particularly important to soil-water relationships. Clayey soils may cause perched water table due to low horizontal and vertical movement. Sandy soils may be well-drained or may have high water table due to physiographic location. In wetland tillage (puddling), initial soil moisture determines how the soil will be saturated/flooded. Structural-stability is also a function of soil texture which comes into play in wetland tillage practices. Fine textured soils will form well puddled soils if tilled at the right soil moisture condition.

2.6.2 Soil mineralogy.

Most of the wetland soils in Nigeria are formed in sedimentary deposits that have been pre-weathered and sorted, and thus may be lacking in primary minerals. The sand and silt fractions have been found to be very siliceous (Okusami *et al.* 1987).

The clay mineralogy of wetland soils is very important because of its effect on the physico-chemical properties of soils, viz, water - and nutrient-holding capacities, organic matter retention, structural development and consistence to mention some of the significant ones. The 2:1 mineral types are more desirable than the 1:1 types but most lowlands of the tropics, river flood-plains included, are formed in materials derived from the highly weathered catchment area, hence they reflect the mineralogy of the highly weathered stable upland sections of the physiography.

2.6.3 Nutrient requirements of rice.

The nutrients required by rice crop are nitrogen, phosphorus, potssium, sulphur, calcium, magnessium and silicon (Chang, 1978) while the micro-nutrients needed are iron, manganese, boron, copper, molybdenum and zinc. Silicon is not considered as an essential nutrient involved in the physiological processes of crops but it is included in the nutrition of rice for its structural property (increasing the straw strength). It has, however, been shown that considerable yield increase results from the application of silicon to rice soils, especially on the sandy or high organic matter soils. This increase in yield has been attributed to the fact that silicate ion displaces phosphate ion from the exchange sites making the latter more available. In addition, some workers (e.g. Okuda and Takahashi; 1964) postulate that silica mitigates toxicity that will result from excess Fe, Mn, and/or Al in the growth medium. Okuda and Takahashi related silicon significance to the number of panicles, number of spikelets per panicle and the percentage of ripened grains.

2.6.4 Soil salinity.

Salinity is a problem in floodplain soils. The salt content will depend on the soil type as well as its age and the climate of the region. Clayey soils contain higher percentages of salts than sandy soils. Salt accumulates as water evaporates from lakes and swamps with the self-sealing processes considerably enhancing the ponding of surface water. Relatively young stream sediments contain less salt than older sediments.

The groundwater of major river floodplains is generally highly saline. The presence of salts in these soils is most likely as a result of shallow groundwater table. Repeated wetting and drying (as plants draw H_2O) subsequently lead to precipitation of salts. Occurrence of perched water table might be enough to keep seasonal precipitation from leaching accumulated salts from the s oil. If so, salts would continue to concentrate and Na might replace Ca on the exchange si tes (Al-Janabi and Lewis, 1982).

Soil and land suitability requirements of rice (FAO, 1978) include $<$4% slope, $>$50cm soil depth, very poorly drained to moderately well drained environment, silt loam/clay loam, montmorillonitic soils, moderate inherent fertility, a specific conductance of less than 2 dS m^{-1} at 25^{o}C, and pH of 5.2 to 7.5 (1:2.5 H_2O). The optimum temperature response of photosynthesis in rice is 25 - 30^{o}C. Sorghum on the other hand, can tolerate a specific conductance of up to 5dSm^{-1} at 25^{o}C, with pH of 5.2 to 8.5 (1:2.5 H_2O), and moderately well drained to well drained soil donditions (FAO, 1978).

CHAPTER THREE

3.0 ENVIRONMENTAL FEATURES OF THE STUDY SITES.

3.1 Physical setting of the study area.

The area used for the study lies between Makurdi in the south, Lumda in the northeast, and Argungu in the northwest. The coordinates are approximately latitudes 7°45'N (Makurdi) and 12°50'N (Argungu), and longitudes 4°30'E (Argungu) and 13°45'E (Lumda). The sites for field work were areas around Makurdi, Gadza (near Bida), Dwam (near Numan), Argungu, and Lumda (near Dikwa). These represent Guineo-Congolian (Makurdi and Gadza), Sudanian undifferentiated woodland (Dwam and Argungu), Sudanian/Sahelian transition (Lumda) savanna respectively (Fig. 1).

Makurdi site is located approximately 11km west of Makurdi, near Otave village. It is on the floodplain of River Benue. The floodplain is about

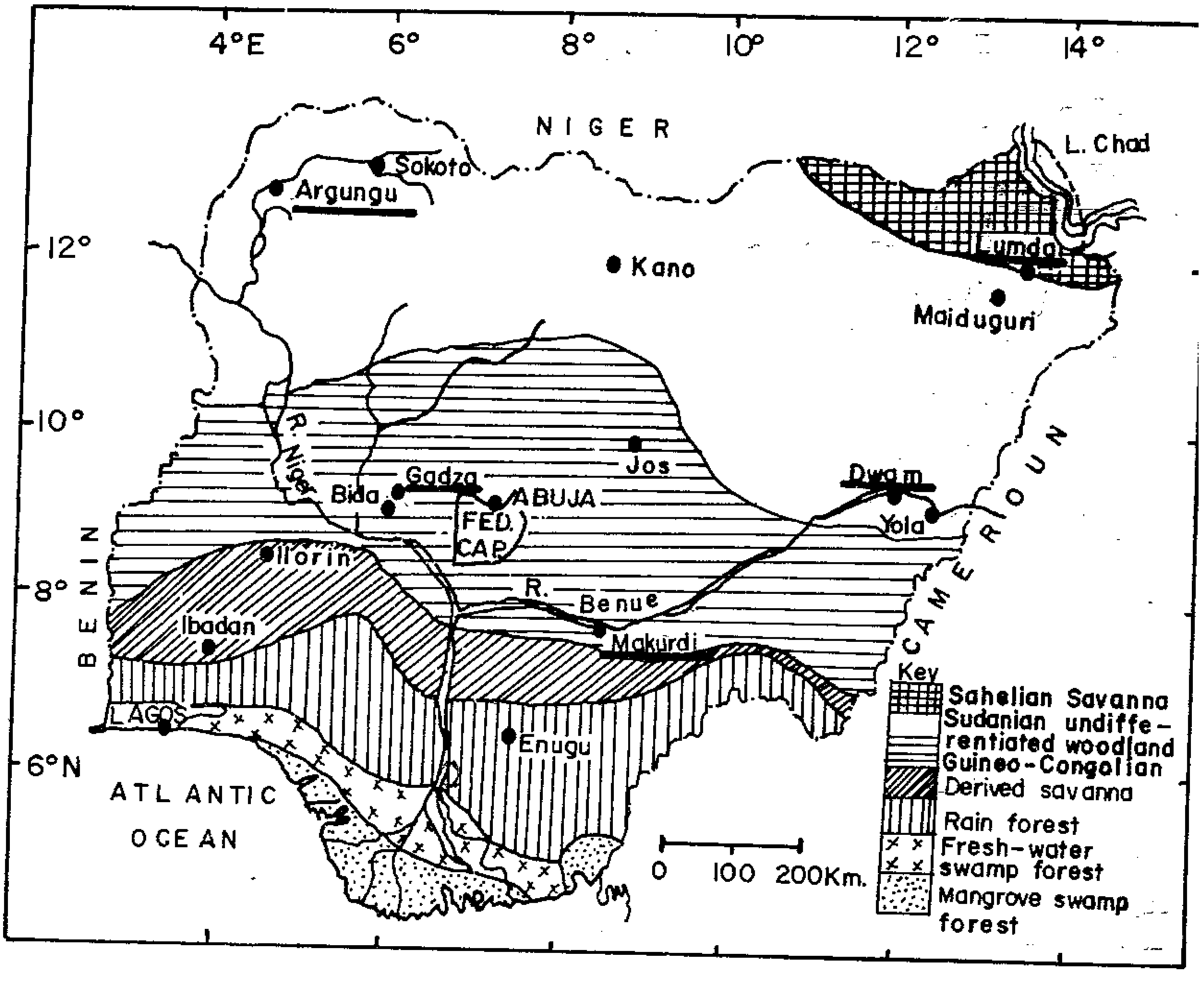


Fig. 1: Vegetational map of Nigeria showing sampling sites (underlined)
(Adapted from: White, F. 1983. Unesco / AETFAT / UNSO Vegetation map of Africa)

4km. wide (from the river to the upland) and has an elevation of 80 metres. Gadza is an inland valley, and is located about 7km. east of Bida. The valley is a tributary to Gadza river, while the latter is a tributary of River Niger. Length of the cross section (from the valley bottom to the crest) of the valley at the study site is approximately 5.7km. The transect lies on elevations ranging from 96 metres (valley bottom) to 130 metres (summit or crest). The major settlements along the valley are Gbansitako and Gadza.

Dwam site is on the floodplain of River Benue. It is 53km from Yola, off Yola-Gombe road and is on about 2.6km transect from the river to the upland. It is on about 150 metres elevation. The site used at Argungu is on the floodplain of River Sokoto. It is about one kilometre from the bridge on River Sokoto, at Argungu. The floodplain is about 8km wide (from the river to the upland) at the study site and has an elevation of about 200 metres. Lumda site is 2.7km from Lumda on Maiduguri-Dikwa road. In the western part of the area is an irregular pattern of sand dunes, their orientation having been largely obscured by erosion and flooding. The site is, however, devoid of rock outcrops. The site is on about 320 metres elevation.

3.2 Climate

Generally, the climate of the study area is under the influence of both the southwest monsoon and the northeast trade winds (Grove, 1970). The area has a hot subhumid tropical climate. Makurdi area has a relatively weak bimodal rainfall pattern (Fig. 2) with peaks in both July and September (Fagbami and Vega-Catalan, 1985). Mean annual rainfall is approximately 1300mm (Kowal and Knabe, 1972), mean annual air temperature is about 27°C, and mean daily relative humidity is about 75%. The mean annual rainfall at Gadza is about 1175mm. (data for Bida) with a unimodal pattern of distribution. The mean annual air temperature is approximately 27°C and mean

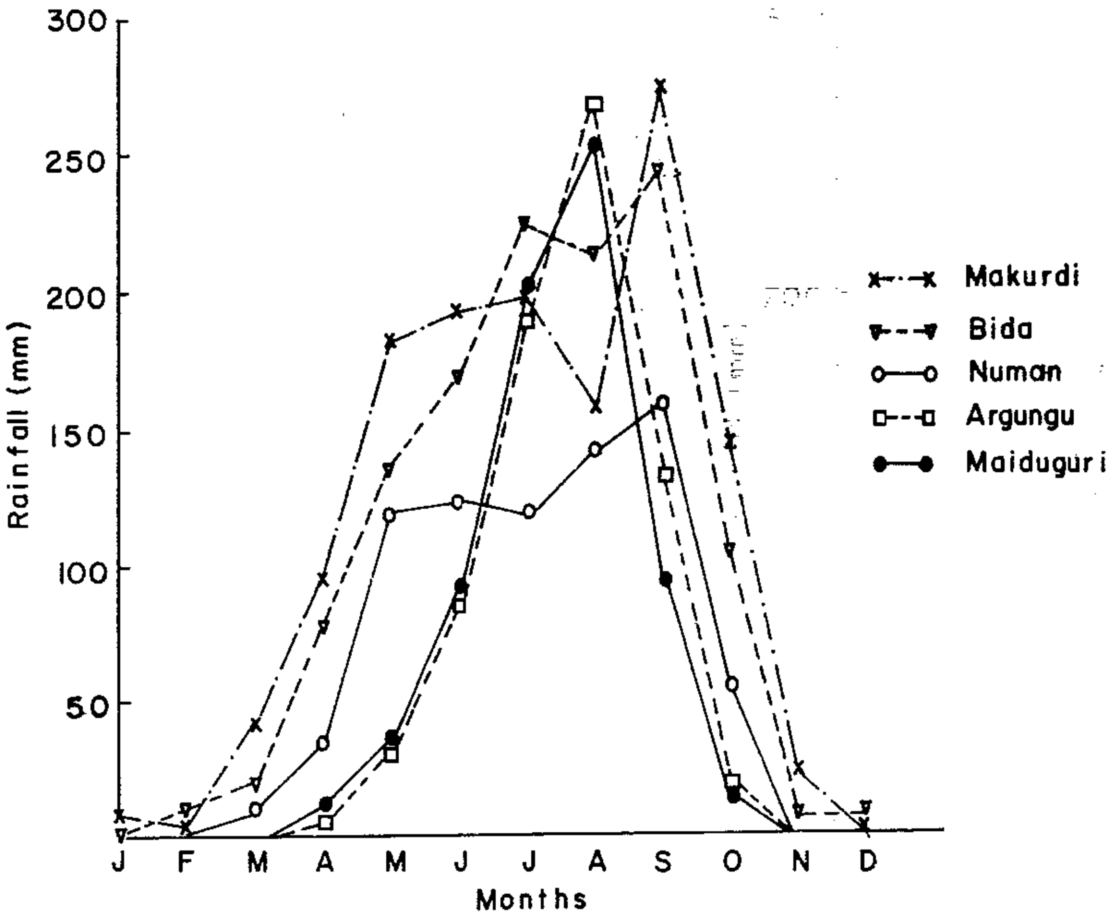


Fig. 2 : Mean monthly rainfall for five stations near the sampling sites (Adapted from : Kowal, J. M. and Knabe, D. T. 1972. An Agroclimatological Atlas of the northern states of Nigeria).

daily relative humidity is about 70%.

At Dwam and Argungu, rains normally start between April and June and stop about September of October. The rainfall pattern indicates a unimodal trend. Mean annual rainfall in Dwam (data for Numan) is about 800mm while in Argungu is about 700mm (Kowal and Knabe, 1972). The two locations (Dwam and Argungu) have mean daily relative humidity of about 55% and the mean air temperature of about 28°C (Udo, 1978). During the months of November to March, the northeast trade wind brings harmattan.

Lumda has a hot subhumid tropical climate with a fairly wide seasonal and diurnal range of temperature. The climatic regime consists of a long dry season followed by a shorter wet season. The onset and close of rains is quite variable. The rainfall pattern is similar to that of Argungu. As the monsoon weakens, there is a short hot season followed by the onset of harmattan wind. During the harmattan period, relative humidity falls to 20% or less in the hottest part of the day. Air temperature during the day at this period is about 32°C and, under completely cloudless skies. The nights can be cold with temperatures ranging between 5° and 10°C. The relative humidity remains low except immediately after rainstoms.

3.3 Vegetation and land-use.

The vegetation of the whole study area can be described generally as savanna woodland, consisting of comparatively light tree growth with a more or less continuous oover of grasses. Both Makurdi and Gadza sites have similar vegetation pattern, with scattered trees. The most common trees are sheabutter (*Vitellaria paradoxa*) and oil palm (*Elaeis guinensis*). Dwam has a relative more continuous cover of grasses, with some African fan palms (*Borassus aethiopium Mart.*).

Around Argungu and Lumda, there are differences in vegetation and land-use depending on such factors as soil types, and seasonal or permanent flooding. Four local vegetation landuse patterns were recognised around Argungu. These are African rice (*Oryza glaberrima* Steud), wild rice varieties; thorny species of *Acacia albida*, *Acacia laeta*, and *Acacia nilotica*; and African fan palms (*Borassus aethiopium* Mart). At Lumda site, the local vegetation communities are 'Firki' (clay-flat), Tabki (pond) and sahel. Firki communities occur on the clay-flats which are very extensive around Lake Chad. These areas are submerged during the wet season and the vegetation consists of various species of grasses, mostly annuals. However, these Firki communities are used for cultivation of 'Firki' sorghum. Tabki communities occur in semi-permanent ponds with clayey substrata. They carry a denser vegetation than their surroundings. Thorny species of Acacia such as nilotica are common in these areas. The trees of sahel zone are fine-leafed with *Acacia sp.* most common. Two types of palm trees, *Borassus aethiopium* and *Hyphaene thebaica* are in pure stands in some depressions (Barber, 1965; White, 1983). The grasses are mainly *Andropogon sp.* *Hyparrhenia sp*; *Schizachyrium sp*; and *Pennisetum sp.*

3.4 Geology

Detailed geological studies of the study area had been undertaken by Russ (1930), Pugh and King (1952), Barber (1965), and Adeleye and Dessauvagie (1970). Three main formations have been identified in Makurdi area: (i) the Cretaceous Makurdi sandstone on the south bank of River Benue and (ii) its contemporary Kaena sandstone which forms the northern shoulder of the Benue valley; (iii) the dark/gray Awgu shale that underlies the western third of the northern shoulder. The floodplain is a Quarternary sediment (Pugh and King, 1952). The parent rock in Gadza area is Nupe sandstones (Russ, 1930). It consists of Cretaceous feldspathic sandstone and siltstone. Ironstone capped hills (mesas) are common. The interbedded oolitic ironstone seems to be of sedimentary origin, with iron possibly introduced after deposition. The upper oolitic ironstone may partly have a lateritic origin and may therefore occur at different levels above the sandstone (Adeleye and Dessauvagie, 1970).

Dwam is underlain by limestone-shale series (Dukul Formation) recognized by Falconer (1911) in the the Yola-Muri area which he assigned to the lower Turonian. Beds of blue/gray black shales are interbedded with thin limestones (Carter et al., 1963). The shales weather to form 'black cotton soil,' which is a black clayey soil with high shrinkage capacity. In many localities, the presence of Dukul Formation can often be inferred from the occurrence of 'black cotton soil' and limestone debris (Barber, 1965). Argungu is underlain by massive white clay interbedded with coarse-to medium-grained red sandstone (Kogbe, 1973), mudstone and organic materials. The floodplain is underlain by Tertiary sediment.

Lumda is on Chad Formation for which a possible Pliocene - Pleistocene age has been suggested (Barber, 1965). The sediments are of lacustrine origin and vary lithologically both laterally and vertically. The bulk of the deposit is argillaceous gray and blue-gray clay but well defined sandy horizons do occur.

In more recent times, dune sands accumulated and several ancient dune systems can be recognised. The Chad Formation has been penetrated at several localities. It is underlain by rocks of the basement complex, and Cretaceous shales. A bore-hole at Muna (which is not far from the study site) at kilometre 19, Maiduguri-Dikwa road, went to 550 metres and was bottomed on hard sandstones (Barber, 1965).

CHAPTER FOUR

4.0 MATERIALS AND METHODS

4.1 Field study

One transect in each of the study sites (i.e Makurdi, Gadza, Dwam, Argungu and Lumda) was selected for soil characterization. Soil profile pits were excavated on different physiographic positions depending on the landform. A total of twenty-three (23) profile pits were excavated. Makurdi transect had five profile pits sited on the levee, levee/backswamp transition, backswamp, lowland/upland fringe, and upland; and they were labelled pedons MD1, MD2, MD3, MD4 and MD5 respectively. Six profile pits, subsequently labelled pedons GZ1, GZ2, GZ3, GZ4, GZ5, and GZ6, were excavated on the valley bottom, valley fringe, middle and upper slopes (upland) at Gadza. Upland soils were included in the sampling to serve as reference points. At Dwam, three profile pits, viz, pedons DM1, DM2 and DM3 were excavated on three different positions of the landscape and were formed in different parent materials; while Argungu transect had six profile pits (pedons AR1 to AR6) that occupied different positions of the landscape and with different vegetation communities. Three profile pits, subsequently labelled pedons LD1, LD2, and LD3, were excavated on different parent materials with different vegetation communities (Firki, Tabki and Sahel). Pedons LD1 and LD2 were on plains whereas pedon LD3 occupied a sand ridge.

The profiles were described (Appendix A) following the recommended procedure in 'Guidelines for soil profile description' (FAO, 1977) using horizon designations of Soil Survey Staff (1981). Soil samples were collected from the identified horizons for laboratory analysis.

4.2 Laboratory analyses.

4.2.1 Physical and chemical analyses.

The soil samples collected were air-dried, gently crushed, and sieved to separate the fine earth fraction ($<$2mm) from coarse materials.

Particle size analysis of the soils was done by hydrometer method (Bouyoucos, 1962). The proportions of sand, silt and clay were obtained from the hydrometer readings after which the textural class was determined using a textural triangle. The clay-free sand and silt fractions of each horizon were calculated as follows:

$$\text{clay-free sand} = \frac{\%\ \text{sand}}{(\%\ \text{sand} + \%\ \text{silt})} \times 100$$

and

$$\text{clay-free silt} = \frac{\%\ \text{silt}}{(\%\ \text{sand} + \%\ \text{silt})} \times 100$$

Bulk density was determined by clod method (Blake, 1965) using paraffin wax melted at 60 - 70°C. The bulk density (D_b) was calculated from the following formula:

$$D_b = \frac{dw \quad Wods}{\left(Wsa - Wspw + Wpa - \left(\frac{Wpa \quad dw}{dp} \right) \right.}$$

where

dw = density of H_2O at temperature of determination (25°C),

Wspw = net weight of soil sample plus paraffin in water,

Wpa = weight of paraffin coating in air,

dp = density of paraffin (approximately 0.9),

$$Wods = \frac{Wsa}{1 + (P/100)}$$, oven-dry weight of soil sample (clod or ped),

Wsa = net weight of soil sample in air

P = percent water, on an oven-dry basis, found in the subsample.

Soil pH was determined in both distilled water and 1.0M KCl (1:1, soil: solution ratio) using pH-meter (Beckmann Expandomatic SS-2) after equilibration for 30 minutes. Exchangeable bases (Ca, Mg, Na and K) were extracted with neutral 1.0M NH_4OAC. Calcium and Mg in the extract were analyzed by atomic absorption spectrophotometry (Perkin - Elmer model 703), while Na and K were determined with a flame photometer. Exchange acidity was determined by titration method using 1.0M KCl for extraction (Mclean, 1965). Effective cation exchange capacity (ECEC) is the summation of NH_4OAC extractable bases (Ca, Mg, Na and K) plus KCl - extractable Al and H. The determination of CEC was by sum of cations method, that is, acidity by 0.5M $BaCl_2$ - 0.055M Triethanolamine (TEA) pH 8.2 plus bases by 1.0M neutral NH_4OAc (Soil Conservation Service, 1984). Exchangeable Mn and easily reducible Mn (ERMn) were analyzed by atomic absorption spectrophotometry; however, while exchangeable Mn was extracted with neutral 1.0M NH_4OAc, 1.0M NH_4OAc containing 0.2% hydroquinone was used to extract the easily reducible Mn. Exchangeable cations and cation exchange capacity values are expressed in cmol(+)kg^{-1} soil (1 cmol(+)kg^{-1} soil = 1 meq/100g of soil). Electrical conductivity (EC) test for soluble salt concentration of the soil samples was determined in distilled water (1:2, soil: H_2O ratio) at 25°C using a conductivity meter (Karl Kolb model) after allowing the paste to stand for one hour. Solutions of 0.01M KCl (having EC of 1.412 dSm^{-1} at 25°C; 1 dSm^{-1} = 1mmho/cm) and 0.10M KCl (having EC of 12.900dSm^{-1} at 25°C) were used as standard reference solutions. Organic carbon was determined by the Walkley - Black method (Allison, 1965) using soil samples that were ground to pass through 0.05mm sieve (IITA, 1979). Determination of total nitrogen in soil samples was by Macro-Kjeldahl method (Bremner, 1965) using orthophosphoric plus sulphuric acid mixture for digestion at 370°C for 3 hours in Tecator digestor system (IITA, 1982), with N estimated by Technicon's (AAII) auto-analyzer. Available P was extracted by the Bray No 1 method (Bray and Kurtz, 1945) and determined by Technicon's (AAII) auto-analyzer.

The dithionite-citrate-bicarbonate (DCB) method (Mehra and Jackson, 1960) was used for extracting free Fe, Al, and Si. For the determination of oxalate extractable or 'amorphous' Fe, Al, and Si, Tamm's reagent (acidified ammonium oxalate, pH 3.0) and the extraction procedure described by Mckeague and Day (1966) were used. The amounts of Fe extracted by the two procedures (DCB and NH_4 - oxalate) were determined by atomic absorption spectrophotometry (AAS); Al was by colorimetry (modified aluminon) method (IITA, 1979); and Si was analyzed colorimetrically (IITA, 1979). The concentrations of the elements (Fe, Al, and Si) are expressed as oxides viz; $Fe_2O_{3(d)}$, $Al_2O_{3(d)}$, and $SiO_{2(d)}$ for DCB extraction; and $Fe_2O_{3(o)}$, $Al_2O_{3(o)}$ and $SiO_{2(o)}$ for oxalate extraction.

Total elemental analysis was by the Na_2CO_3 fusion method (Kanehiro and Sherman, 1965). Samples were ground into fine powder to pass through 100 mesh sieve, and soil sample: Na_2CO_3 ratio of 1:5 was fused in a platinium crucible at 950°C for about 3 hours. The solidified melt was then dissolved in 50ml 6.0M HCl and then made to 250ml volume with distilled water. Total elemental concentrations of Si, Al, Fe, Mn, Mg and Ca were determined by atomic absorption spectrophotometry (AAS), while K was determined by flame photometry. After the fusion, some of the soil samples (high in Si) gave gelatinous orange colour appearance. Twenty millilitres of these (gelatinous orange colour) extracts were then dissolved in 6.0M NaOH to get clear solution for elemental determination. The total elemental concentration are expressed as oxides viz; $SiO_{2(+)}$, $Al_2O_{3(+)}$, $Fe_2O_{3(+)}$, MnO(t), MgO(t), $K_2O(t)$ and CaO(t).

4.3 Mineralogical analysis.

4.3.1 Particle separation:

Particle separation was done by the combined method of wet and dry sieving, sedimentation and decantation (Jackson, 1956). Sand separation was by wet sieving using a 50 micron nylon sieve supported on a glass funnel to deliver into 1000ml cylinder. The thoroughly dispersed and freshly stirred soil suspension was allowed to stand for 40 seconds and was then decanted through the sieve. All grains were then washed into the sieve by means of a coarse jet of water. The remaining silt and clay were washed from the sand on the sieve by means of a coarse jet of water until a clear washing solution comes through the sieve and funnel. The sand fractions ($>$50 microns) were carefully transferred to a pyrex crucible, dried in the oven at 105°C for 24 hours (Brewer, 1960), weighed and preserved in desiccator for further fractionation.

4.3.2 <u>Sand fractionation.</u>

A set of four sieves - 1000, 450, 225, and 75 microns, were arranged in the order listed. The dried sands ($>$ 50 microns fraction) were poured into the upper 1000 microns sieve, thus after 21 manually applied strokes the sand particles were separated into 2.0 - 1.0mm, 1.0 - 0.45mm, 0.45 - 0.225mm, 0.225 - 0.075mm, and 0.075 - 0.05mm sand fractions; these represent very coarse, coarse, medium, fine and very fine sand fractions respectively on the United States Department of Agriculture (USDA) particle size scale. Each fraction was weighed and preserved.

Soil samples suspected to contain high iron oxide coatings were pretreated by the dithionite-citrate-bicarbonate (DCB) method (Mehra and Jackson, 1960) to remove the iron oxide coatings before the samples were dispersed, and fractionated.

Silt and clay separation:

The suspension of silt and clay particles ($<$ 50 microns) was made up to 1000ml with distilled water and vigorously stirred. The principle of Stoke's law was used to calculate the time of sedimentation of silt particles. At 25°C (room temperature), 2 microns particles settled through water for a depth of 30cm mark from the liquid surface at a sedimentation period of 20 hours, 39 minutes. The suspension above the 30cm mark (clay fraction) was carefully siphoned into a beaker with application of little suction, using a long rubber tubing. The clay fraction obtained was kept for X-ray analysis. The remaining liquid over the sedimented silt fraction was drained off by tilting the cylinder. The silt fraction was removed with some distilled water and strong agitation of the cylinder into a pyrex crucible, and dried in an oven at 105°C for 24 to 48 hours. It was then kept for X-ray analysis.

4.3.3 Petrographic studies of fine sand fraction.

Separation of light and heavy mineral fractions:

The fine sand fraction (.225 - .075mm) was further separated into light and heavy mineral fractions. Bromoform (s.g = 2.89) was filtered through an 11cm Whatman 42 filter paper into a 100ml separating funnel up to maximum diameter level. The fine sand fraction was added and thoroughly stirred with a glass rod. After three hours, the heavy grains (s.g $>$ 2.89) were obtained by running the sample plus bromoform through a filter paper under suction in a filter funnel over a Buchner flask. The grains were then washed with acetone and dried. The light mineral fraction (s.g $<$ 2.89) was also collected in the same way.

Grain mounts and slide preparation:

A drop of canada balsam (R.1 = 1.54) was placed on a glass slide, and with a microspatula enough subsample of the fine sand fraction was taken to ensure uniform coverage of an area about 22mm square on a glass slide. This was covered with a cover glass. Identification of minerals was made according to their optical properties (e.g. colour, shape, pleochroism, birefringence, and extinction). Grain counts were made and amount of individual mineral grain count is expressed as percentage of total grains counted.

4.3.4 X-ray analysis of the silt fraction.

The dried silt fraction (.05 - .002mm) was ground into very fine powder by using an agate mortar. The modified form of the wedge method for random orientation and Back-filled box mount (Jackson, 1956) was prepared by filling the recess of the wedge with the sample. The surface of the mounted sample was carefully smoothened until it formed a sharp edge flush with the lower side of the stainless metal wedge. The mounted samples were then X-rayed using a Phillips X-ray diffractometer with Fe-Kα radiation (wavelength of 0.1937nm).

4.3.5 X-ray analysis of the clay fraction.

Sample pre-treatment and saturation of exchange complex:

Clay separates ($<$ 2 microns) of the soil samples were segregated after the removal of organic matter with 30% hydrogen peroxide (H_2O_2), and iron oxides by the dithionite-citrate-bicarbonate (DCB) procedure of Mehra and Jackson (1960).

The clay suspension was divided into two 50ml polythene centrifuge tubes. Half of this was saturated with Mg using 1.0M Mg-acetate ($Mg(OAc)_2$) in a method described by Dixon (1982). The clay fraction in the other 50ml centrifuge tube was saturated with potassium (K), using 1.0M KCl for saturation in the same manner as for Mg-saturated samples.

Mounting as oriented aggregates:

The oriented aggregates of the Mg-and K-saturated samples were prepared by the Glass-Plate technique (Whittig, 1965), using pipette method after adding sufficient water to the sample to ensure complete dispersion. Glass microscope slides (2.6 x 4.6cm) were used. As much of the suspension as can be held by the film tension was added and allowed to dry completely at room temperature.

Solvation with ethylene glycol:

Half of the Mg-saturated sample slides were later glycolated with ethylene glycol vapour for four hours in a desiccator. The ethylene glycol was heated to boiling point and quickly poured into the petri-dishes arranged below a metal gauze (on which the sample slides were arranged) in a desiccator.

Heating at 110°C, 300°C and 550°C.

The K-saturated sample slides were heated in an oven at 110°C for four hours, and later in a muffle furnace at 300°C for three hours. After cooling, the slides were subjected to X-ray diffractometry analysis i.e. X-rayed after 110°C heating and also after 300°C treatment. The same slides were later heated at 550°C for four hours, and then cooled.

X-ray diffractometry (XRD) analysis was performed on all the sample slides after treatments consisting of Mg-saturation (air-dried), Mg-saturation (glycolated), K-saturation (air-dried), and heating at temperatures up to 110°C, 300°C, and 550°C using a Phillips X-ray diffractometer with iron (Fe-Kα) target. The scanning range was $2^{o}2\theta$ to $35^{o}2\theta$.

Interpretation of the X-ray diffractogramms was by measurement of diffraction spacings (the d-spacings) and reference to standard tabulated diffraction spacings of minerals. The quantities of minerals present were estimated from diffractometry intensity by measuring the relative height of diffraction peaks and the width-at-half peak height. The peak height multiplied by width-at-half peak height proposed by Karathanasis and Hajek (1982) was used to calculate the peak areas.

4.4 Potential Productivity Ratings.

The soils were rated for swamp rice production. The multiplication model of land productivity index was adopted. It is in line with Storie index but with appropriate modifications to reflect the soil, drainage and other land-surface factors limiting the cultivation of swamp rice and dry season cropping (of sorghum) in the selected wetland soils.

The following ratings used for soil depth and drainage were obtained by modifying the ratings of FAO (1965) in order to reflect the special water requirements of swamp rice.

Ratings for soil depth and drainage.

	Criteria	Ratings
1.	Water-logged or deep poorly drained swamp soils	1.00 100
2.	Deep poorly-drained soils	0.80
3.	Deep somewhat poorly-drained soils	0.75
4.	Shallow, poorly-drained soils	0.60
5.	Deep excessively drained loamy sand soils (Regosols)	0.40 - 0.50
6.	Deep, well-drained soils	0.40

In assigning ratings for soil texture of the plough layer (20cm of the surface), the influence of stoniness on workability, availability of nutrients and moisture, and development of roots were considered.

The following ratings proposed for texture by FAO (1965) were adopted.

	Criteria	Ratings
1.	Soils with over 61% stones and gravels.	0.10
2.	Soils with 41-60% stones and gravels.	0.11 - 0.30
3.	Loamy sand with 30-40% gravel	0.45 - 0.55
4.	Loamy sand with 20-29% gravel	0.56 - 0.74
5.	Loamy sand with 10-19% gravel	0.75 - 0.80
6.	Loamy sand with <10% gravel	0.81 - 0.84
7.	Sandy loam with 30-40% gravel	0.46 - 0.65
8.	Sandy loam with 20-29% gravel	0.66 - 0.78
9.	Sandy loam/sandy clay loam with 20-29% gravel.	0.70 - 0.75
10.	Sandy loam with 10-19% gravel	0.76 - 0.80
11.	Sandy loam with <10% gravel	0.81 - 0.85
12.	Clay loam with <10% gravel	0.86 - 0.90
13.	Sandy clay with <10% gravel	0.96 - 0.97
14.	Sandy clay loam with <10% gravel	0.98 - 0.99
15.	Sandy clay/sandy clay loam with <10% gravel.	1.00

The nutrient retention ability of soils is a function of the clay mineral or the cation exchange capacity of the various clay types. Ratings for nature of clay were assigned according to FAO (1965).

	Criteria	Ratings
1.	Soils with mainly kaolinite and sesquioxides	0.90
2.	Soils with mixture of clays for hydrous micas.	0.95
3.	Soil with mainly smectite and allophane.	1.00

The presence of weatherable minerals within 200cm of the soil profile has been considered as one of the conditions of high fertility (Young, 1976). The following ratings were proposed for mineral reserve based on the amount of weatherable minerals in sand fraction.

Criteria		Ratings
1.	Low reserve ($<$10% weatherable minerals).	0.85
2.	Fair reserve (11-30% weatherable minerals).	0.95
3.	High reserve ($>$30% weatherable minerals).	1.00

Salinity has been considered as one of the problems of wetland soils especially those of flood-plains (Al-Janabi and Lewis, 1982). The following ratings were proposed for salinity condition based on soil and land requirements of rice (FAO, 1978).

Criteria	Ratings
EC (at 25^{o}C) of 0-0.2dSm^{-1}	1.00
EC of 0.2 - 1.0dSm^{-1}	0.75 - 0.84
EC of 1.0 - 2.0dsm^{-1}	0.50 - 0.74
EC of 2.0 - 4.0dSm^{-1}	0.40
EC of $>$4.0 dSm^{-1}	0.10

The following ratings were proposed for rainfall condition based on the environmental requirements for rice production.

Criteria	Ratings
Mean annual rainfall of 1501 - 2000mm.	0.81 - 1.00
Mean annual rainfall of 1001 - 1500mm.	0.71 - 0.80
Mean annual rainfall of 750 - 1000mm.	0.51 - 0.70
Mean annual rainfall of 500 - 750.	0.30 - 0.50
Mean annual rainfall of $<$500mm.	0.10

The potential productivity index was calculated as:

P = D.T.A.M.S.R.

where

P = Potential productivity index,

D = Soil depth and drainage,

T = Soil texture,

A = Nature of clay,

M = Mineral reserve,

S = Salinity,

R = Rainfall condition.

The potential productivity indices were expressed as fractions.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

5.1 General soil properties.

5.1.1. Soil morphology and landform relationship.

The Makurdi site is a river floodplain consisting of levee, backswamp, and upland (Fig. 3a). Schematically, the landform of Gadza consists of upper slope, middle slope and lowland positions (Fig. 3a). The different physiographic positions contain different soil types. Dwam transect consists of soils formed in alluvial, shale-dominated, colluvial/ limestone materials respectively. The limestone-derived soils occupy higher landform position, whereas, on the lowland portions, soils are developed in the shale/clay materials. The upland (limestone) abruptly grades into shale/clay lowland.

Both Makurdi and Argungu have similar landforms. However, the landform at Argungu site appears more complex, having two levees (distal and proximal, Fig 3b)

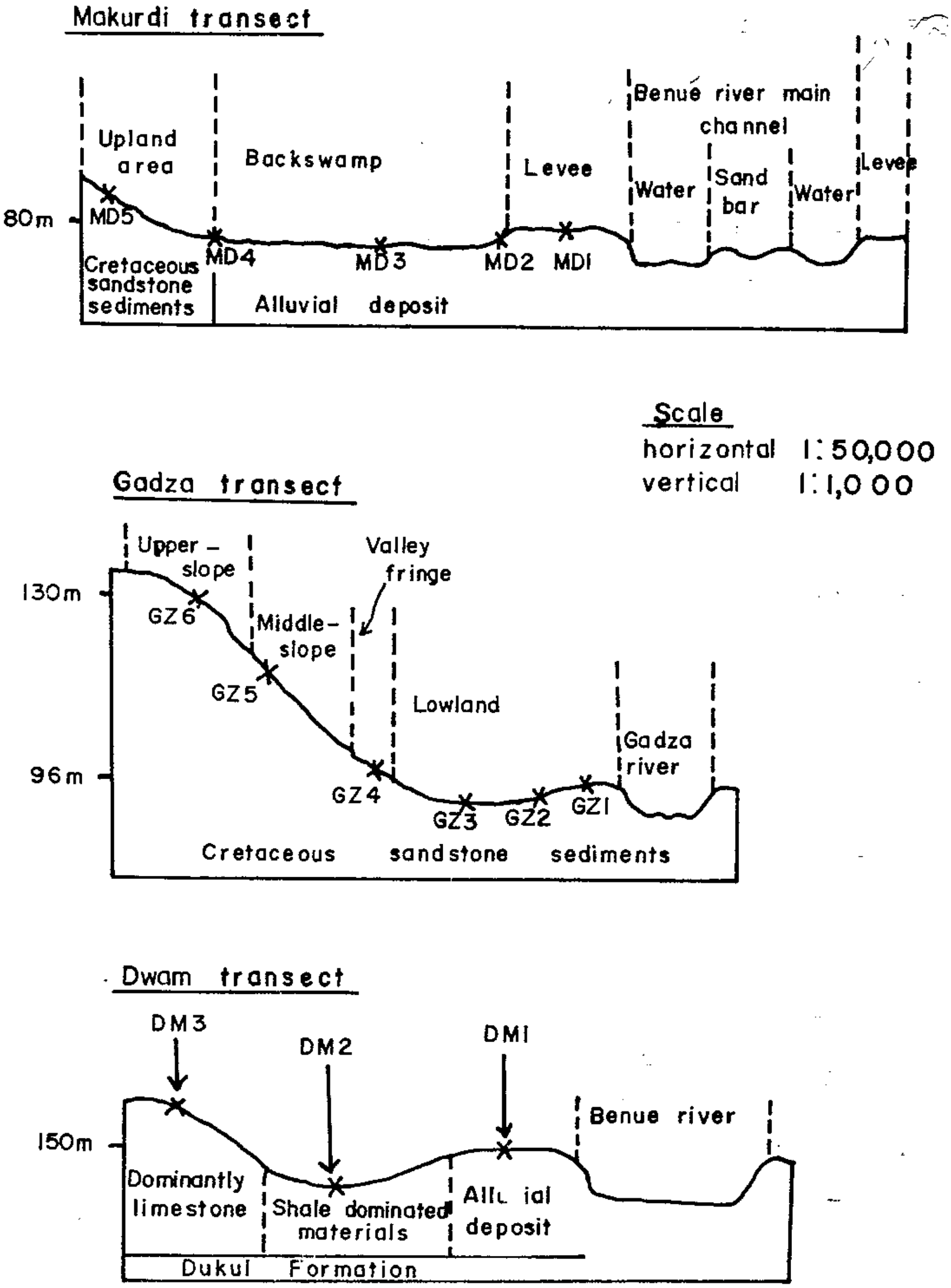
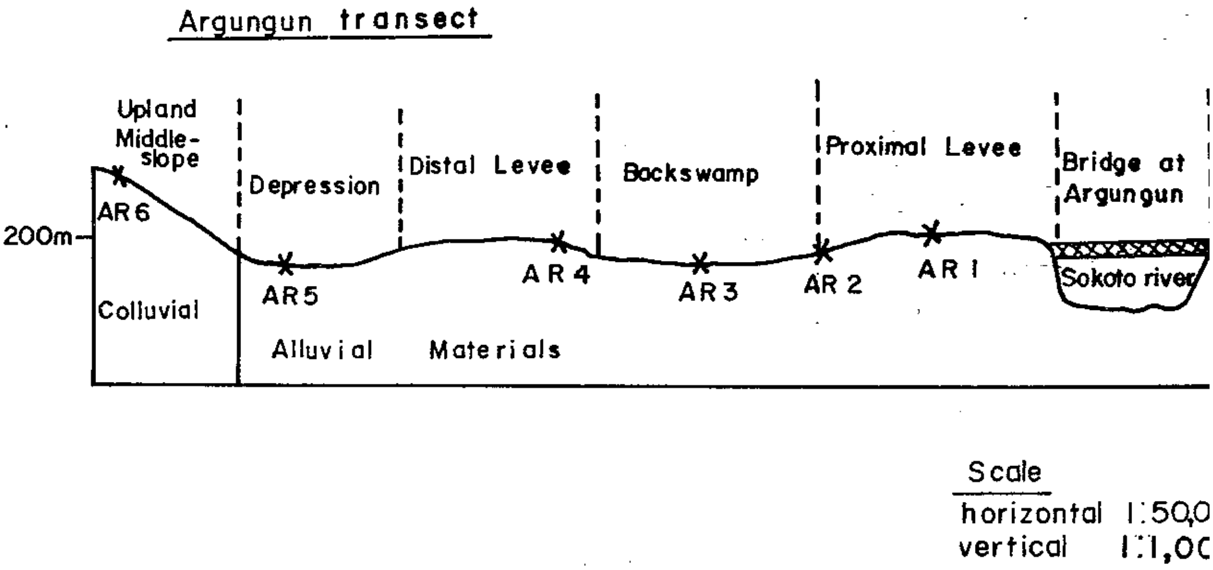


Fig. 3a : Schematic landforms and location of profiles of Makurdi, Gadza and Dwam transects.



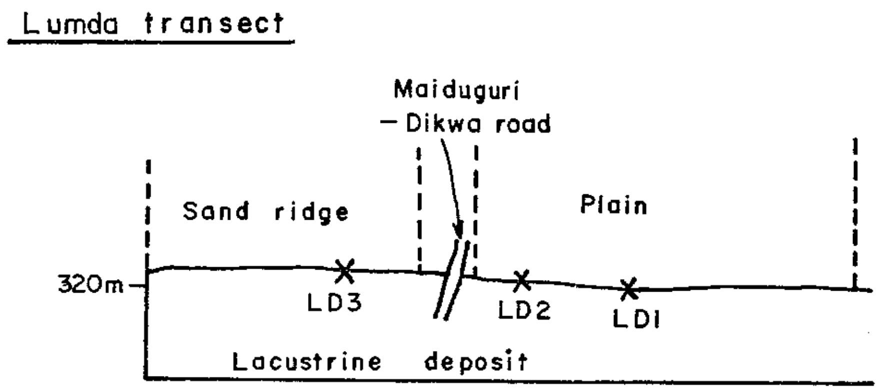


Fig. 3b : Schematic landforms and location of profiles of Argungun and Lumda transects.

and is made up of Tertiary sediments (Kogbe, 1973). The landform of Lumda transect consists of a series of plains and a sand ridge. The plains consist of shale-dominated parent materials occupying a slightly lower elevation than the shale/sand mixed parent materials. Sand materials occupy a higher elevation.

The different physiographic positions contained soil types formed in different parent materials. Morphological properties of the pedons sampled are given in the profile descriptions (Appendix A). Pedon MD1 which occupied the levee had brownish colour and was mottle-free whereas pedons MD2, MD3 and MD4 were grayish and mottled below the epipedon. Pedon MD5 which is an upland soil had red subsoil. Pedons MD2, MD3 and MD4 are considered hydromorphic because of the preponderant mottles. Low chroma was typical of pedons MD3 and MD4 but in addition pedon MD4 had nodules and concretions. Formation of mottles involves oxidation and reduction of Fe and Mn compounds (Veneman <u>et al.</u> 1976), and is favoured by the seasonal fluctuating water table and flat topography of the site.

The presence of nodules/concretions in pedon MD4 indicates rapid changes in aeration and concordant fluctuations of redox potential in the soil. When the diffusion of oxygen throughout the soil is limited by increasing moisture content, the redox potential drops and compounds containing Fe and Mn would become reduced (Gotoh and Patrick, 1974). Iron and Mn are mobilized by reduction and can contribute to the formation of mottles or concretions when the soil environment becomes more oxidised during subsequent drying cycles. The physiographic position of pedon MD4 (lowland/upland fringe) is also a contributing factor to the presence and abundance of mottles. Pedon MD1 owes its high groundwater table to the water level of River Benue. Angular and subangular blocky structures were common.

In Gadza transect, pedon GZ1 which occupied a physiographic position similar to that of pedon MD1 also had brownish colour. It was, however, mottled below the epipedon. This most probably indicates influence of fluctuating groundwater table. Pedon GZ2 had a permanently high groundwater table that becomes shallower during the rainy season; grayish colour with low chroma, and was free of mottles. This is an evidence of gleization. Apart from the presence of mottles in pedon GZ3, it had similar morphology to pedon GZ2. Field observations showed a zone of saturation at 96-111cm (2BA horizon) depth. Pedon GZ4 which occupied the valley fringe had a brownish colour with high chroma and was mottled below the epipedon. The sizes and contrasts of the mottles (Appendix A) indicate great influence of alternating wet/dry soil conditions. The spherical shape of the ironstone pebbles and boulders observed at 93 - 169cm (BC horizon) soil depth may be ascribed to past erosional processes and deposition. The upland soils (pedons GZ5 and GZ6) had distinctly red hues (2.5YR and 5YR) and were free of mottles. The decreasing redness of soils downslope can be ascribed to increasing hydration of iron content as explained by Torrent et al (1984), and Schwertmann (1985). Ironstone pebbles and boulders were observed at 140-182cm (2Bt2 horizon) and 160-200cm (2C horizon) soil depths in pedons GZ5 and GZ6 respectively. Morphologic differences between pedons GZ5 and GZ6 were slight, because they both had free internal drainage. The dominant structure in all the six pedons on Gadza transect was subangular blocky.

All the three pedons of Dwam transect had morphological features which were completely different from one another. Pedon DM1 had brownish colour and was mottled below the epipedon. The preponderant black Mn/Fe nodules/concretions and occurrence of mottles reflect the influence of alternating wet/dry conditions and fluctuations of redox potential in the soil. The major distinguishing feature of pedon DM2 which occupied a depression is the occurrence of some vertic properties. The soil had about 3cm wide cracks that extended from the soil surface to about 42cm depth and had pressure surfaces (slickensides) in the subsoil. The pedon is characterised by seasonal moisture deficit sufficient to induce cracking. Soil displacement, as evident by the presence of slickensides, had been attributed to differential wetting in the subsoil (Dasog *et al.*, 1987). The pedon had weak horizon development and mottled grayish colour. The third pedon of the transect (pedon DM3) had brownish colour, and was well-drained and free of mottles because it occupied a higher elevation with free internal drainage. It had a subsoil material of consolidated limestone. The wide disparity in the morphological features of soils of Dwam transect reflects the geology of the study site (limestone-shale series) (Falconer, 1981). Pedon DM1 is formed in alluvium, pedon DM2 had characteristics of 'black cotton soils' derived from shale, while pedon DM3 is formed in limestone.

Pedons AR1 and AR2 were brownish in colour with preponderant low contrast mottles. In addition, sesquioxidic nodules/concretions characterized pedon AR1. A zone of saturation occurred at the subsoil horizons of pedon AR1 and the pedon owes its poor drainage condition to the water level of River Sokoto. Pedon AR3 had brownish gray colour and was mottled below the epipedon. Sesquioxidic nodules/concretions were common features of $2Bwcg_1$ (85-118cm) and $3Bwcg_2$ (118-160cm) horizons of this pedon. Pedon AR4 which occupied the levee (distal/natural levee) was pale brownish in colour with distinct mottles. This indicates that the soil is influenced by seasonal alternating wet and dry moisture conditions. Pedon AR5 had morphological features similar to those of pedon AR4, except that the Bt_1 (40-71cm depth) and Bt_2 (71-110cm depth) horizons of pedon AR5 were very sticky and plastic, whereas the corresponding horizons in pedon AR4 were not, due to the high clay content contained in pedon AR5 (Fig 4b). Pedon AR6 was brownish and mottled below the epipedon. Although subangular blocky was the dominant structure in all pedons of Argungu transect, the clayey surface horizons of pedon AR3 and the Bt_1 (40-71cm) and Bt_2 (71-110cm) horizons of pedon AR5 were angular blocky.

Pedons LD1 and LD2 had similar morphologic features but the vertic properties were more developed in pedon LD1 because of its higher smectite content (Table 5). Both pedons were dark gray in colour and mottled in parts of horizons adjoining cracks, particularly near the bottom of the cracks. The presence of slickensides in their subsoil horizons, and cracks that opened to the soil surface attest to the presence of expanding clay types. Pedon LD1 had many wide (about 7cm) cracks whereas pedon LD2 had 2cm wid cracks. Pedon GZ4 which occupied the valley fringe had a brownish colour with high chroma and was mottled below the epipedon. The sizes and contrasts of the mottles indicate great influence of alternating wet and dry soil conditions. The upland pedons of Makurdi and Gadza transects (pedons MD5, GZ5 and GZ6) had dinstinctly red hues (2.5YR and 5YR) whereas those of Dwam and Argungu transects were brownish in colour. The decreasing redness of soils downslope could be asdribed to increasing hydration of iron content as explained by Torrent et al. (1984). Soils of levees (e.g. pedons MD1, AR1 and AR4) and the valley fringe (pedon GZ4) were sandy whereas those of backswamps (e.g. pedons MD2, MD3 and AR3) were clayey. This reflects the influence of floodwater flow rate and deposition. The sandy texture of all pedons of Gadza transect could be associated with the sandstone-derived parent materials. Also, the clayey texture of pedons DM2, LD1 and LD2 has to do with the influence of their shale-containing parent materials rather than the topography.

5.1.2 Physical and chemical properties.

Appendix B shows the bulk density and particle size distribution data of the pedons. Pedon MD1 which occupied the levee in Makurdi transect had loamy sand texture whereas the other pedons in the transect were clayey. The bimodal clay distribution in pedons MD1 and MD3, and the irregular pattern observed in pedon MD2 could be an indication of a redistribution of the finer soil materials or be related to the deposition history (Fig. 4a). However, in pedon MD5 the amount of clay increased with soil depth. The textural diversity shown between pedon MD1 and the other hydropmorphic pedons MD2, MD3, and MD4 is probably due to the floodwater flow rate. Pedon MD1 parent materials

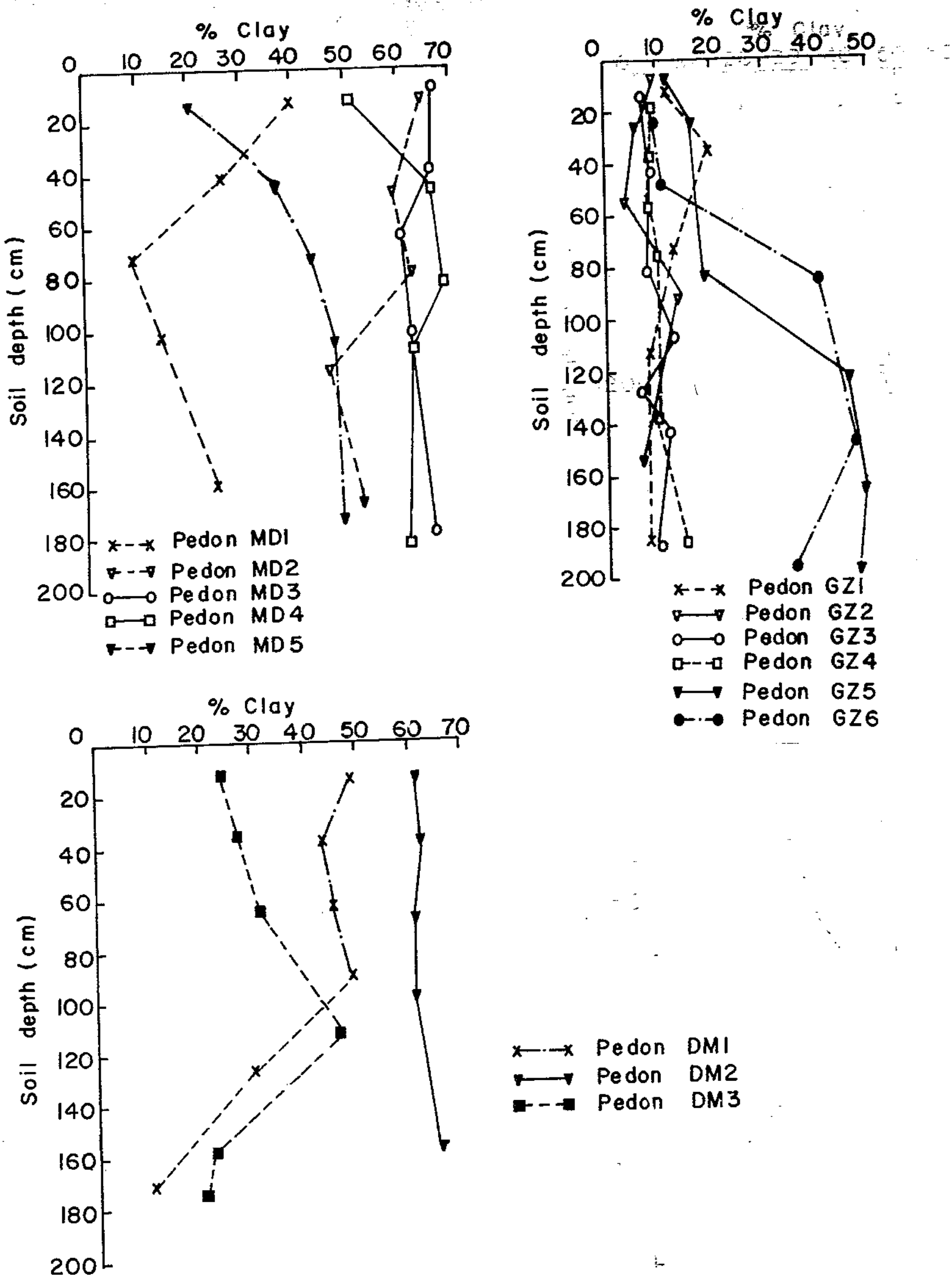
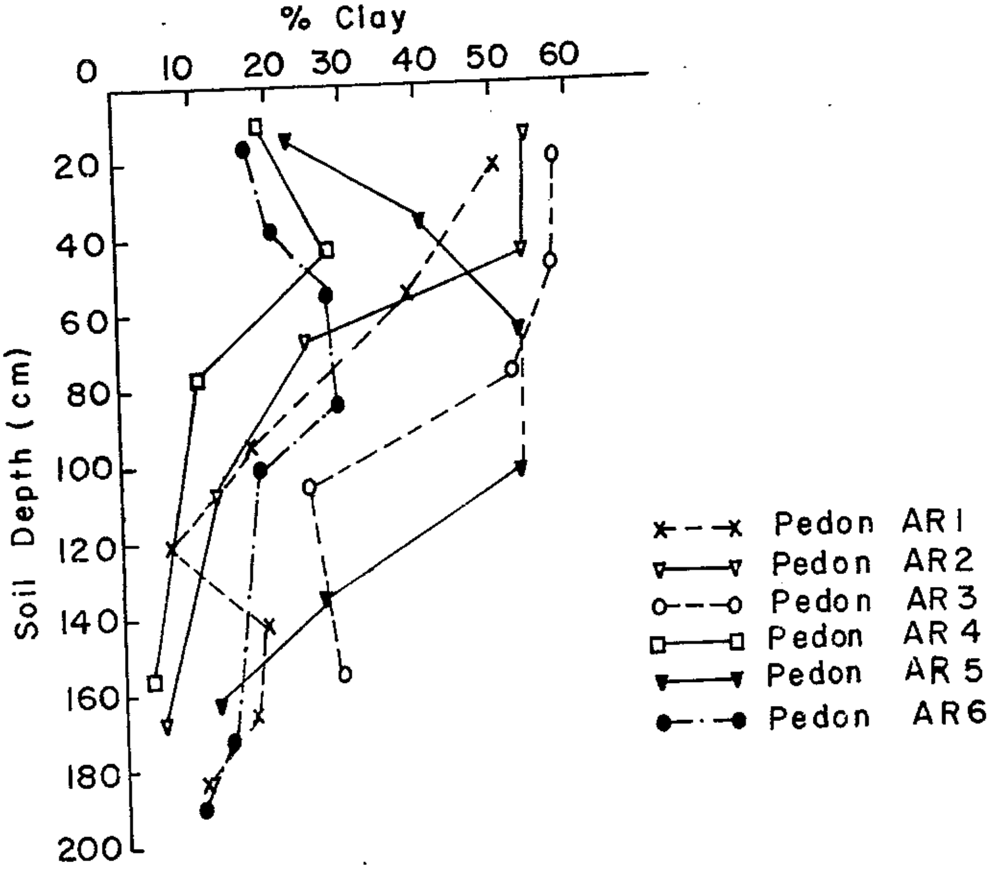


Fig. 4a : Clay distribution with soil depth of pedons on Makurdi


% Clay
0
10
20
30
40
50
60
20
40
60
80
100
120
140
160
180
200
Soil Depth (cm)
Pedon AR1
Pedon AR2
Pedon AR3
Pedon AR4
Pedon AR5
Pedon AR6


% Clay

were deposited at a period of high flood since they are dominantly made up of sand-size fractions (Appendices B and C). The finer soil particles of the other pedons were probably in suspension and transported for a longer time, over greater distances and deposited at a low flood period, when there was less turbulence than those of pedon MD1. The higher amounts of clay contained by the hydromorphic pedons MD2, MD3 and MD4 than the upland pedon MD5 corroborates the influence of transportation and deposition of fine soil particles over great distances at a low flood period. In addition, pedons MD2, MD3 and MD4 contained higher amounts of silt-size particles than sand.

The lowland soils of Gadza transect (i.e. pedons GZ1 to GZ4) are generally loamy sand to sandy loam. Pedons GZ5 and GZ6 which are of course upland soils, had loamy sand epipedon and sandy clay subsoil i.e the clay-size fraction increased with soil depth. The presence of argillic horizons in pedons GZ5 and GZ6 was established from the eluvial-illuvial clay ratio even though the presence of clay cutans was observable only with difficulty. The sandy texture of the soils of Gadza transect can be ascribed to the geology (sandstone) of the area.

Pedon DM1 that occupied a levee/backswamp position had silty clay epipedon and loamy subsoil whereas pedon DM2 which occupied a depression had clayey texture throughout the profile. In pedon DM3, the B horizons contained higher clay contents than both A and C horizons (Fig 4a). The wide textural diversity shown among the pedons of Dwam transect could be related deposition history and/or type of parent material. The pattern of clay distribution in pedon DM1 is most probably due to the floodwater flow rate (i.e. deposition of fine soil particles at a low flood period) whereas the clayey texture of pedon DM2 is an indication of the strong influence exerted by the shale-dominated parent material. Presence of argillic horizons in pedon DM3 was established from the clear clay increase in the B horizons and presence of clay cutans. In Argungu transect, pedons AR1 and AR4 have sandy textures. Both pedons are on proximal -

and distal/natural - levee respectively. The pattern of soil particle distribution in pedons AR2 and AR3 whereby clay accumulated at the surface (Fig. 4b) is a reflection of the floodwater flow rate and deposition of fine soil particles. In pedons AR5 and AR6, the clay content increased with depth with evident clay increase in the B horizons. In addition, they contained clay cutans in their B horizons (Appendix A).

The textural class of pedon LD1 was clay; that of pedon LD2 was sandy clay loam to sandy clay while pedon LD3 was sandy loam. This reflects the influence of parent materials of the soils of Lumda transect. Pedon LD1 (with its shale-dominated parent material) occupied a slightly lower elevation than pedon LD2 which has shale/sand mixed parent materials. Pedon LD3 occupied a higher elevation and is formed in sand materials.

Table 1 shows some selected chemical properties of the pedons. Soil reactions of the pedons of Makurdi transect ranged from medium acid, pH 5.6 - 5.9

Table 1: Selected chemical properties of the pedons

Horizon	Depth (cm)	pH (H_2O)	ECEC	CEC (pH8.2)	EC dSm^{-1}	Organic C (%)	Total N (%)	Bray-1P (ppm)
			cmol (+)kg^{-1}soil					
	Makurdi transect							
Pedon MD1; Typic Ustifluvent								
Ap_1	0-24	6.5	3.73	9.83	0.4	0.49	0.05	3.6
A_2	24-59	6.4	4.10	13.53	0.3	0.21	0.04	2.3
$2BA_1$	59-87	6.5	2.03	5.67	0.1	0.19	0.02	2.1
$2BA_2$	87-120	6.5	2.83	7.61	0.3	0.20	0.03	2.2
2BC	120 168	6.4	3.39	8.35	0.2	0.16	0.02	1.8
Pedon MD2; Typic Udifluvent								
A	0-25	4.2	4.15	9.87	0.2	0.48	0.05	2.7
BA	25-60	6.3	2.20	7.04	0.3	0.26	0.03	1.4
Bw_1	60-97	6.2	2.25	7.83	0.2	0.34	0.04	2.2
Bw_2	97-130	6.2	3.29	11.51	0.2	0.39	0.05	2.1
BC	130-171	6.4	4.09	11.67	0.1	0.37	0.05	1.6
Pedon MD3; Andaqueptic Fluvaquent								
A	0-30	4.9	6.69	25.44	0.1	0.75	0.08	5.9
BA	30-45	5.2	4.88	16.02	0.2	0.22	0.03	2.6
$2Bw_1$	45-70	5.9	5.55	12.98	0.2	0.37	0.05	2.8
$2Bw_2$	70-113	6.1	8.73	25.51	0.2	0.18	0.03	1.9
$2BC_g$	113-182	5.8	7.44	24.72	0.3	0.23	0.03	2.3
Pedon MD4; Aquic Kandiustult								
A	0-22	5.3	4.31	14.24	0.1	0.76	0.08	2.9
BA	22-64	5.6	3.93	10.60	0.2	0.19	0.03	0.8
Bwc_1	64-90	6.2	4.63	14.55	0.2	0.21	0.04	1.0
Bwc_2	90-128	6.2	3.78	9.80	0.2	0.09	0.02	0.5
BC_g	128-185	6.3	4.58	14.11	0.2	0.11	0.03	0.6

Table 1 Continued

Horizon	Depth	pH (H_2O)	ECEC	CEC (pH8.2)	EC dSm^{-1}	Organic C (%)	Total N (%)	Bray-1P (ppm)
			cmol(+)kg^{-1}soil					
Pedon MD5; Typic Kandiustalf								
A	0-26	6.4	5.43	12.35	0.3	0.43	0.06	2.3
BA	26-59	6.3	2.95	6.63	0.2	0.08	0.02	1.2
Bt_1	59-80	6.2	3.35	8.46	0.3	0.06	0.02	1.1
Bt_2	80-124	6.2	3.78	9.04	0.5	0.05	0.02	1.0
C	124-185	6.3	3.99	11.89	0.3	0.06	0.02	1.2
Gadza transect								
Pedon GZ1; Typic Tropaquept								
A	0-21	4.2	3.20	8.47	0.2	0.53	0.05	11.4
BA	21-52	4.8	2.26	5.22	0.2	0.14	0.05	4.3
Bw	52-95	5.2	2.75	5.43	0.3	0.16	0.04	1.5
BC	95-129	5.9	2.75	5.30	0.2	0.01	0.02	2.3
C_g	129-192	5.9	1.96	3.16	0.3	0.03	0.02	2.0
Pedon GZ2; Typic Tropaquept								
Ap	0-11	4.4	2.38	6.03	0.1	0.20	0.02	3.4
AB_1	11-32	5.2	2.45	6.92	0.2	0.07	0.02	1.8
AB_2	32-60	5.3	2.85	8.57	0.3	0.07	0.01	1.5
2BA	60-110	5.0	3.04	11.00	0.2	0.30	0.02	2.5
$2C_g$	110-168	5.1	2.71	9.45	0.2	0.06	0.01	3.4
Pedon GZ3; Typic Tropaquept								
A	0-18	4.2	2.93	8.63	0.1	0.22	0.03	2.5
AB_1	18-55	5.1	2.57	5.28	0.1	0.06	0.01	1.3
AB_2	55-96	5.3	2.62	6.02	0.3	0.11	0.01	0.9
$2BA_1$	96-111	5.0	3.04	10.54	0.3	0.36	0.02	1.2
$2BA_2$	111-136	5.2	2.43	3.88	0.2	0.08	0.02	2.1
2BC	136-151	4.9	2.76	6.04	0.1	0.33	0.03	2.0
2C	151-192	4.9	1.92	3.46	0.1	0.04	0.02	4.2

Table 1 Continued

Horizon	Depth (cm)	pH (H_2O)	ECEC	CEC (pH8.2)	EC dSm^{-1}	Organic C (%)	Total N (%)	Bray-1P (ppm)
			cmol(+)kg^{-1}soil					
Pedon GZ4; Aquic Quartzipsamment								
Ap	0-20	5.3	2.14	9.65	0.2	0.31	0.03	1.9
AB_1	20-40	5.3	2.05	8.39	0.3	0.20	0.04	1.2
AB_2	40-60	5.2	1.61	4.57	0.2	0.09	0.03	1.1
BA	60-93	5.0	1.09	4.12	0.2	0.12	0.01	1.0
BC_1	93-169	5.3	1.71	4.89	0.2	0.03	0.01	1.2
$BCrg_2$	169-192	5.4	1.86	5.27	0.2	0.01	0.01	0.8
Pedon GZ5; Typic Kandiustult								
A	0-14	5.7	2.04	7.36	0.4	0.30	0.02	1.4
AB	14-37	5.1	2.04	7.70	0.2	0.11	0.02	1.1
BA	37-92	4.8	2.06	7.73	0.1	0.07	0.02	1.1
$2Bt_1$	92-140	5.0	3.38	8.34	0.2	0.09	0.02	0.7
$2Bt_2$	140-182	5.0	4.80	8.91	0.1	0.12	0.03	0.6
2C	182-207	5.1	3.39	7.89	0.1	0.07	0.03	0.6
Pedon GZ6; Typic Kandiustult								
A	0-24	5.5	2.36	6.54	0.2	0.24	0.03	2.3
AB	24-59	4.9	1.88	5.03	0.1	0.15	0.03	2.6
$2Bt_1$	59-97	4.9	2.37	8.25	0.2	0.12	0.03	1.0
$2Bct_2$	97-160	5.0	1.34	2.89	0.1	0.07	0.03	0.8
2C	160-200	5.0	1.61	3.30	0.1	0.06	0.02	0.7
Dwam transect								
Pedon DM1; Tropaquent								
A	0-25	6.2	29.83	62.84	0.3	0.41	0.06	2.7
BAc	25-44	6.1	19.02	46.02	0.2	0.33	0.03	1.9
Bwc_1	44-72	6.2	23.19	53.72	0.2	0.25	0.05	1.6
$2Bwc_2$	72-103	6.4	23.77	50.64	0.1	0.20	0.04	1.5
$2Bwc_3$	103-135	6.7	19.26	45.98	0.5	0.05	0.03	4.8
2C	135-179	6.9	5.08	16.14	0.6	0.04	0.02	4.0

Table 1 continued

Horizon	Depth (cm)	pH (H_2O)	ECEC	CEC (pH8.2)	EC dSm^{-1}	Organic C (%)	Total N (%)	Bray-1P (ppm)
			cmol (+)kg^{-1}soil					
Pedon DM2; Udic Chromustert								
A	0-20	6.0	24.78	55.67	0.2	0.42	0.04	2.5
AB	20-42	6.8	28.05	58.20	0.5	0.40	0.03	1.6
Bw_1	42-74	6.8	27.88	57.67	0.3	0.31	0.03	2.3
Bw_2	74-109	7.1	30.68	64.33	0.7	0.14	0.04	1.8
BC	109-165	7.8	31.46	68.81	1.1	0.34	0.02	1.2
Pedon DM3; Typic Kandiustalf								
A	0-18	7.3	6.03	23.24	1.0	0.13	0.03	3.0
AB	18-43	6.6	4.10	14.30	0.6	0.09	0.02	2.4
Bt_1	43-76	5.5	3.86	9.55	0.3	0.08	0.02	1.2
$2Bt_2$	76-120	5.1	6.51	19.07	0.3	0.05	0.02	1.2
2C	120-160	6.8	8.24	26.67	0.2	0.06	0.02	0.9
R	160-175+	8.2	10.87	39.48	0.2	0.06	0.02	0.7
Argungu transect								
Pedon AR1; Andaqueptic Fluvaquent								
A	0-35	4.7	11.85	39.54	0.2	0.73	0.07	3.0
AB_1	35-61	5.3	10.64	32.16	0.2	0.43	0.04	1.8
$2AB_2$	61-101	6.4	6.64	21.04	0.2	0.02	0.02	1.2
$2Bwcg_1$	101-128	6.7	3.91	9.87	0.3	0.02	0.01	1.5
$2Bwcg_2$	128-157	7.2	5.63	13.60	0.5	0.05	0.01	0.9
$2BCg_1$	157-173	6.8	4.88	11.48	0.4	0.08	0.02	1.8
$2BCg_2$	173+	6.1	10.30	33.01	0.3	0.09	0.02	1.2
Pedon AR2; Andaqueptic Fluvaquent								
A	0-24	5.7	12-53	43.81	0.2	0.55	0.06	1.3
Bw_1	24-50	5.9	12.44	41.38	0.1	0.13	0.03	0.9
$2Bw_2$	50-77	6.0	6.75	25.40	0.2	0.03	0.02	1.1
$2BC_1$	77-110	6.2	4.48	9.56	0.2	0.05	0.02	1.9
$2BC_2$	110-179	6.2	1.67	3.00	0.2	0.03	0.01	4.9

Table 1 (contd.)

Horizon	Depth (cm)	pH (H_2O)	ECEC	CEC (pH8.2)	EC dSm^{-1}	Organic C (%)	Total N (%)	Bray-1P (ppm)
			cmol(+)kg^{-1}soil					
Pedon AR 3; Tropaquent								
A	0-31	5.5	20.73	48.22	0.5	0.56	0.04	0.9
BA	31-58	5.7	24.14	53.21	0.5	0.43	0.05	0.8
Bw_1	58-85	6.1	22.15	51.64	0.8	0.37	0.05	0.8
$2Bwcg_2$	85-118	7.6	9.71	32.30	1.4	0.03	0.02	1.1
$3Bwcg_3$	118-160	7.4	9.88	31.84	2.0	0.03	0.02	0.9
3BCg	160-194	7.3	1.50	4.24	1.2	0.04	0.01	0.3
Pedon AR4; Typic Ustropept								
A	0-18	4.9	4.72	12.06	0.2	0.53	0.07	7.7
Bw	18-50	5.6	9.14	34.45	0.2	0.17	0.03	1.5
BC	50-85	5.3	3.30	7.92	0.1	0.05	0.02	2.1
C	85-170	5.9	1.36	3.96	0.2	0.02	0.01	3.1
Pedon AR5; Albaquic Paleudalf								
A	0-21	5.6	8.34	22.53	0.6	0.51	0.06	2.4
BA	21-40	6.9	13.04	35.84	0.8	0.31	0.05	1.8
Bt_1	40-71	8.0	12.36	29.67	4.1	0.06	0.03	1.2
Bt_2	71-110	7.2	7.69	21.00	1.2	0.03	0.02	1.0
BC_g	110-140	6.5	1.38	3.61	0.7	0.03	0.01	2.4
2C	140-165	6.1	2.79	6.10	0.5	0.09	0.02	8.4
Pedon AR6; Kanhaplic Haplustalf								
A	0-22	5.5	3.76	8.92	0.2	0.37	0.05	5.1
Bt_1	22-41	5.9	12.79	36.44	0.3	0.28	0.06	2.4
Bt_2	41-59	5.6	12.21	31.56	0.2	0.24	0.03	1.3
Bt_3	59-88	5.3	8.89	26.00	0.2	0.15	0.02	1.2
BC	88-113	5.7	4.22	9.84	0.2	0.03	0.02	1.2
C	113-180+	6.6	1.05	2.62	0.2	0.06	0.01	2.4

Table 1 (contd.)

Horizon	Depth (cm)	pH (H_2O)	ECEC	CEC (pH8.2)	EC dSm^{-1}	Organic C (%)	Total N (%)	Bray-1P (ppm)
			cmol(+)kg^{-1}soil					
	Lumda transect							
Pedon LD1; Typic Pellustert								
A	0-18	6.1	28.40	68.59	0.4	0.43	0.05	3.4
AB	18-38	7.1	24.56	51.37	0.8	0.43	0.03	2.6
Bw_1	38-57	7.1	30.80	73.54	1.6	0.41	0.04	1.9
Bw_2	57-96	7.6	31.12	78.20	2.1	0.25	0.03	1.8
2BC	96-119	7.2	22.68	48.81	1.1	0.04	0.04	2.6
2C	119-162	7.6	12.01	31.43	0.9	0.32	0.02	2.4
Pedon LD2; Typic Chromustert								
A	0-14	5.1	6.83	15.31	0.2	0.19	0.04	3.2
2BA	14-44	5.9	16.29	48.27	0.3	0.13	0.04	1.4
$2Bw_1$	44-85	6.6	17.35	46.0C	0.5	0.14	0.02	0.9
$2Bw_2$	85-117	7.7	20.31	49.63	1.0	0.09	0.03	1.0
2BC	117-137	8.0	18.44	37.71	1.8	0.05	0.02	0.7
2C	137-181	8.1	11.45	24.08	2.0	0.10	0.02	1.0
Pedon LD3; Oxic Ustropept								
A	0-24	6.6	12.74	38.62	0.5	0.57	0.05	1.2
AB	24-44	7.2	22.78	53.16	0.5	0.41	0.04	0.8
$2Bw_1$	44-56	8.0	30.09	69.05	0.8	0.22	0.05	0.6
$2Bw_2$	56-85	8.3	30.90	71.28	4.0	0.24	0.04	0.8
$2Bw_3$	85-115	7.7	35.20	72.01	1.5	0.07	0.03	3.0
2CB	115-160	7.7	24.93	49.80	1.5	0.04	0.02	3.2

(pedons MD3 and MD4) to slightly acid, pH 6.3 - 6.4 (pedons MD1, MD2 and MD5). Soils of Gadza transect exhibited more acid reactions (Table 1). Soil reaction ranged from strongly acid, pH 5.2 (pedons GZ2, GZ3, and GZ4, mostly hydromorphic) to very strongly acid, pH 4.8 (pedons GZ1, GZ5 and GZ6).

Soils of Dwam transect exhibited soil reactions ranging from strongly acid, pH 5.5 (pedon DM3) through slightly acid, pH 6.1 (pedon DM1) to neutral, pH 6.8 (pedon DM2). This reflects different leaching environments and parent materials. The lower horizons of pedons DM2 (109 to 165cm) and DM3 (160 to 175cm) showed mildly alkaline (pH 7.4) and moderately alkaline (pH 8.2) reactions respectively. In pedon DM2, this could be attributed to the relatively high values of exchangeable Na and/or Ca whereas the high soil pH of the lower horizon of pedon DM3 is attributed to weathering of calcitic material at this depth. In Argungu transect, the soil reaction ranged from strongly acid, pH 5.3 (pedon AR1) through medium acid, pH 5.6 - 5.9 (pedons AR2, AR3, AR4 and AR6) to neutral, pH 6.9 (pedon AR5). The lower horizons of pedons AR1 (128 to 157cm), AR3 (85 to 118cm) and AR5 (40 to 71cm) had neutral (pH 7.2), mildly alkaline (pH 7.6) and moderately alkaline (pH 8.0) reactions respectively. The soil reaction of pedons LD1 and LD3 was neutral, whereas pedon LD2 had medium acid reaction. In this transect, the soil pH increased with soil depth. The saprolitic horizon (2C) of pedon LD1 had a mildly alkaline (pH 7.6) reaction, whereas the saprolitic horizon of pedon LD2 (137 to 181cm) and the B horizon of pedon LD3 (56 to 85cm) were moderately alkaline (pH 8.1 - 8.3). This could be attributed to high clay contents in pedons LD1 and LD2, the relatively high values of exhhangeable Na and/or Ca in the three pedons, and weathering of the shale-containing parent materials in pedons LD1 and LD2.

If the pH difference, ΔpH (pH - pH_{H_2O}), was calculated for all horizons it would give negative values except for the lower horizons of pedon GZ6 (an upland well-drained soil), suggesting the dominance of silicate clay minerals over oxide minerals (Van Raij and Peech, 1972).

Abundance of silicate clay minerals in the pedons corroborates the negative pH difference. The lower horizons of pedon GZ6 (an upland, well-drained soil) were exceptions. A zero ΔpH obtained in the lower horisons of pedon GZ6 would indicate a system approaching zero point of net charge (Van Raij and Peech, 1972; Keng and Uehara, 1974; Gallez et al; 1976; and Sanchez, 1976).

The distribution of exchangeable cations are also shown in Appendix D. The low exchangeable bases (Ca, Mg, Na and K) generally observed in soils of Makurdi transect could be associated with the soil mineralogy and geology of the area. Low activity kaolinite clay mineral dominates in these soils that are formed in sandstone. Relatively high exchangeable bases obtained in the subsoil horizons of pedons MD3 and MD4 could be linked with the high clay content. Soils of Gadza transect had low exchangeable bases values due to their sandy texture.

Pedon DM1 had high accumulation of bases (29.36 cmol $(+)kg^{-1}$ of soil) at the epipedon and 23.10cmol$(+)kg^{-1}$ of soil at the $2Bwc_2$ horizon (72 to 103cm depth).

This could have resulted from base-rich parent materials and contribution from annual floods. The exchangeable bases content was higher in the subsoils of pedons DM2 and DM3 than in their surface horizons but was highest for the subsoil formed in shale material (pedon DM2). The low exchangeable bases content of pedons AR1 and AR4 could be due to their sandy texture whereas the relatively high accumulation of bases at the surface horizons of the remaining pedons of Argungu transect is associated with clay distribution. High exchangeable bases in pedons of Lumda transect could have resulted from the base-rich parent materials and lack of evidence of leaching (especially in pedons LD1 and LD2). Calcium and magnesium dominated the exchange complex of all pedons. Both exchangeable Na^+ and K^+ were generally low (Appendix D).

Chemical properties reflect the influence of clay content and the clay mineralogy of the different soils. The effective cation exchange capacity (ECEC) of the pedons is shown in Table 1. All pedons of Makurdi and Gadza transects had low ECEC values ranging from 1.09cmol(+)kg^{-1} of soil in BA horizon

(60 to 93-cm depth) to 8.73cmol(+)kg^{-1} of soil in Bw_2 (70 to 113cm depth) horizon of pedons GZ4 and MD3 respectively. The low ECEC corroborates well with their coarse texture (Appendix B). Low clay activity could be inferred from the low exchangeable Ca and Mg values in addition to the dominant kaolinitic clay mineralogy.

Pedons with horizons rich in smectitic clay (pedons DM2, LD1 and LD2) had higher ECEC values. Such horizons include Bw_2 (74 to 109cm depth) or pedon DM2, Bw_2 (57 to 96cm depth) of pedon LD1, and $2Bw_2$ (85-117cm) of pedon LD2 with ECEC values of 30.68, 31.13 and 20.31 cmol(+)kg^{-1} of soil respectively. Pedons DM1 and LD3 had no detectable smectitie but were rich in exchangeable bases, especially Ca and Mg. This may be due to the high clay content of pedon DM1. Pedon LD3 forms on lacustrine deposits and the high Ca content reflects the parent materials. All pedons of Argungu transect and pedon DM3 had relatively low ECEC values. However, horizons with high clay content had higher ECEC values. Such horizons include the upper three of pedon AR3 with ECEC values of 20.73, 24.14 and 22.15cmol(+)kg^{-1} of soil.

Cation exchange capacity (CEC, pH 8.2) values were generally higher than the corresponding ECEC values. This is because of the increase in negative charges due to high pH of the extractant. In most of the pedons sampled in Makurdi, Gadza, Dwam (except pedon DM2), and Argungu, the CEC values generally decreased with soil depth (Table 1). Correlation analysis of the pedons showed that a positive correlation (r = 0.32) exists between CEC and organic carbon content. This probably reflects the contribution of organic matter content (e.g. in pedons MD2, GZ3, DM1 and AR4) to total CEC which Kadeba and Benjaminsen (1976) had reported to account for between 56 and 83 percent of the variations in the CEC of tropical topsoils. In pedons DM2, LD1 and LD2 the influence of clay content and particularly the clay mineralogy appear more prominent than that of organic matter on CEC values. A positive correlation (r = 0.47) also exists between CEC and clay content for the pedons studied.

The difference between (pH 8.2) and ECEC is hereby regarded as the pH-dependent charges (PDC) value. The values of the pH-dependent charges (PDC) are shown in Appendix D. Generally, the PDC decreased with soil depth in the pedons studied. Some subsoil horizons, however, had relatively high PDC values. Such horizons include 2BCg (113 to 182cm depth), 2BA (60 to 110cm depth) BC (109 to 165cm depth) and $2BCg_2$ (173cm +) of pedons MD3, GZ2, DM2 and AR1 respectively. This marked increase in the PDC may point to the presence of amorphous alumino-silicates at depth (Eswaran and Bin, 1978). Close association exists between high PDC and Fe_2O_3(o) and Al_2O_3(o) in $2Bw_2$ (56 to 85cm depth), BC (109 to 165cm depth) and 2BA (60 to 110cm depth) horizons of pedons LD3, DM2 and GZ2 respectively (Table 2 and Appendix D). Mckeague and Day (1966) had reported earlier that high amounts of oxalate extractable Fe and Al are usually associated with horizons having high pH-dependent charges. Soils of Gadza transect had low base saturation (effective) whereas soils of the other transects had relatively high base saturation. Electrical conductivity (EC) values are expressed in dSm^{-1}.

All pedons of Makurdi and Gadza transect had low electrical conductivity (EC) values (Table 1) that ranged between 0.1 and $0.5dSm^{-1}$, whereas pedons DM2 and DM3 had 1.1 and $1.0dSm^{-1}$ EC at their subsoil (109- to 165cm depth) and surface (0- to 18- cm) horizons respectively. Salinity as indicated by EC was greater in the lower horizons of pedons AR3 (118- to 160-cm depth), AR5 (40- to 71- cm depth) and all pedons of Lumda transect. Electrical conductivity measurement suggests that soils with perched water tables (e.g. pedons LD1 and LD2) and those pedons on micro-depressions (e.g. pedons DM2, AR3 and AR5) contained high soluble salts.

The organic carbon content of the surface horizons of the pedons studied ranged between 0.13% (pedon DM3) and 0.76%, (pedon MD4), and decreased with soil depth (Table 1). The generally low organic carbon content of the pedons could be due to the sparse vegetation cover and high rate of organic matter mineralisation during the dry season which incidentally is a longer period in Dwam, Argungu and Lumda than the wet season. The irregular decrease in organic carbon with soil depth observed in pedons MD1 MD2 and MD3 (Table 1) is typical of Fluvents (Soil Survey Staff, 1975). Total nitrogen content of the soils was generally low, ranging between 0.02% (pedon GZ5) and 0.08% (in pedon MD4) in the surface horizons and decreases slightly with soil depth. Available P was generally highest in the surface horizons of all pedons, ranging from 1.2ppm (pedon LD3) to 11.4ppm (pedon GZ1). It decreases with depth, except in pedons GZ2, GZ3, DM1, AR2, LD1 and LD3 which had relatively high P contents in some of their lower horizons (Table 1). High concentration of available P and organic carbon in the surface horizons may imply significant organic or biocycled P in the soils.

There exists a negative relationship between exchangeable Mn and pH in water ($r = -0.38$), and a positive correlation of exchangeable Mn with clay ($r = 0.25$). Mitra and Mandal (1983) noted similar relationships in some rice soils of West Bengal.

Easily reducible Mn (ERMn) had a distribution pattern similar to that of exchangeable Mn.

Generally, the upland soils (pedons MD5, GZ5, GZ6, DM3, AR6 and LD3) had higher ERMn values (46.5 to 53.6ppm) in their surface horizons than the hydromorphic pedons (1.0 to 48.6ppm). This could likely be due to loss of reduced Mn through seepage water.

Table 2 shows the percentages of dithionite-and oxalate-extractable Fe, Al and Si. The dithionite-extractable iron, $Fe_2O_{3(d)}$, represents the amounts of the crystalline and amorphous compounds of Fe occurring freely in the soils. Mehra and Jackson (1960) referred to $Fe_2O_{3(d)}$ as the uncombined or pedogenetic free forms of Fe. Accumulation of free iron oxide in well-drained soils has been associated with lessivage (Asamao, 1973), while in hydromorphic soils, a zone of Fe accumulation is due to fluctuations in water table (Okusami, et al., 1987). Free iron oxide, $Fe_2O_{3(d)}$, shows a different distribution with depth for the five pedons of Makurdi transect. Pedons MD2 and MD3 had an increase in the B horizons. In pedons MD4 and MD5, the

Table 2: Dithionite-and oxalate-extractable Fe, Al and Si distribution of the Pedons

Depth (cm)	DCB extractable Fe_2O_3(d)	Al_2O_3(d)	SiO_2(d)	Oxalate extractable Fe_2O_3(o)	Al_2O_3(o)	SiO_2(o)	$\frac{Fe_2O_3(o)}{Fe_2O_3(d)}$	$\frac{Al_2O_3(o}{Al_2O_3(d}$
	%							
Makurdi transect								
Pedon MD1; Typic Ustifluvent								
0-24	5.06	0.38	1.70	1.94	0.31	0.82	0.38	0.81
59-87	1.89	0.38	1.29	0.23	0.33	0.96	0.12	0.87
120-168	3.89	0.34	2.17	0.89	0.29	0.91	0.21	0.85
Pedon MD2; Typic Udifluvent								
0-25	6.75	0.57	1.77	1.29	0.75	0.93	0.19	1.31
60-97	7.32	0.26	1.21	1.55	0.31	0.81	0.21	1.19
130-171	4.92	0.19	1.88	1.18	0.76	0.94	~~0.94~~ 0.24	4.00
Pedon MD3; Andaqueptic Fluvaquent								
0-30	4.72	0.53	1.89	1.71	0.92	0.85	0.36	1.73
45-70	7.95	0.45	1.63	1.25	0.54	0.73	0.16	1.20
113-182	4.92	0.38	2.59	0.85	0.39	1.26	0.17	1.03
Pedon MD4; Aquic Kandiustult								
0-22	1.83	0.41	1.37	1.11	0.32	0.82	0.61	0.78
64-90	2.66	0.26	1.18	0.51	0.28	0.66	0.19	1.08
128-185	6.06	0.26	2.31	0.50	0.34	1.21	0.08	1.31
Pedon MD5; Typic Kandiustalf								
0-26	3.12	0.23	1.31	0.56	0.12	0.78	0.18	0.52
59-80	4.57	0.11	2.06	0.60	0.08	1.01	0.13	0.73
124-185	5.72	0.11	1.60	0.65	0.05	0.65	0.11	0.45
Gadza transect								
Pedon GZ1; Typic Tropaquept								
0-21	0.51	0.45	1.88	0.19	0.47	0.91	0.37	1.04
52-95	0.08	0.53	1.07	0.10	0.44	0.67	1.25	0.83
129-192	1.23	0.49	1.66	0.09	0.61	0.73	0.07	1.24

Depth (cm)	DCB extractable Fe_2O_3(d)	Al_2O_3(d)	SiO_2(d) %	Oxalate Fe_2O_2(o)	extractable Al_2O_3(o)	SiO_2(o)	Fe_2O_3(o) / Fe_2O_3(d)	Al_2O_3(o) / Al_2O_3(d)
Pedon GZ2; Typic Tropaquept								
11-32	0.03	0.45	1.05	0.04	0.32	0.57	1.33	0.71
60-110	0.20	0.49	1.16	0.20	0.60	0.67	1.00	1.22
110-168	0.03	0.49	1.03	0.06	0.79	0.51	2.00	1.61
Pedon GZ3; Typic Tropaquept								
18-55	0.01	0.45	1.41	0.05	0.92	0.78	5.00	2.04
111-136	0.01	0.53	1.64	0.37	0.85	0.81	37.00	1.60
151-192	0.08	0.53	1.10	0.18	1.20	0.73	2.25	2.26
Pedon GZ4; Aquic Quartzipsamment								
0-20	0.49	0.45	1.32	0.08	0.41	0.88	0.16	0.91
60-93	0.46	0.49	1.33	0.19	0.62	0.73	0.41	1.26
169-192	0.86	0.49	1.63	0.05	0.97	0.82	0.06	1.98
Pedon GZ5; Typic Kandiustult								
0-14	0.97	0.41	2.45	0.04	0.31	1.14	0.04	0.76
37-92	2.71	0.56	2.07	0.06	0.08	0.93	0.02	0.14
182-207	6.69	0.49	3.00	0.16	0.06	1.12	0.02	0.12
Pedon GZ6; Typic Kandiustult								
0-24	1.34	0.45	2.88	0.14	0.07	1.09	0.10	0.15
59-97	10.61	0.53	1.15	0.13	0.09	0.59	0.01	0.17
160-200	9.52	0.49	3.70	0.14	0.02	1.25	0.01	0.04
Dwam transect								
Pedon DM1; Tropaquent								
0-25	5.72	0.41	2.02	0.49	0.46	1.43	0.08	1.12
44-72	4.17	0.30	1.89	0.25	0.88	1.14	0.06	2.93
135-179	2.46	0.30	2.08	0.12	0.37	1.55	0.05	1.23

Table 2 (contd.)

Depth (cm)	DCB extractable Fe_2O_3(d)	Al_2O_3	SiO_2(d)	Oxalate Fe_2O_3(o)	extractable Al_2O_3(o)	SiO_2(o)	$\frac{Fe_2O_3(o)}{Fe_2O_3(d)}$	$\frac{Al_2O_3(o)}{Al_2O_3(d)}$
	%							
Pedon DM2; Udic Chromustert								
0-20	4.83	0.45	1.64	0.36	0.25	0.97	0.07	0.55
42-74	3.92	0.34	1.62	0.21	0.77	0.85	0.05	2.26
109-165	2.29	0.30	1.73	0.01	1.36	1.03	NS	4.53
Pedon DM3; Typic Kandiustalf								
0-18	4.97	0.41	2.36	0.11	0.98	1.80	0.02	2.39
76-120	4.57	0.30	2.77	0.01	0.33	1.94	NS	1.10
160-175+	6.55	0.23	3.32	0.07	0.19	1.14	0.01	0.83
Argungu transect								
Pedon AR 1; Andaqueptic Fluvaquent								
0-35	3.63	0.49	2.65	0.36	0.36	1.00	0.10	0.73
61-101	2.20	0.26	1.09	1.43	0.41	0.52	0.65	1.58
173+	1.74	0.26	3.22	1.17	0.52	1.19	0.67	2.00
Pedon AR2; Andaqueptic Fluvaquent								
0-24	11.81	0.38	3.60	1.31	0.29	1.24	0.11	0.76
50-77	4.03	0.34	2.79	1.19	0.32	0.95	0.29	0.94
110-179	0.77	0.30	2.84	1.10	0.49	1.08	1.43	1.63
Pedon AR 3; Tropaquent								
0-31	6.29	0.53	2.59	0.10	0.56	0.98	0.01	1.06
58-85	4.57	0.23	2.07	0.59	0.66	0.86	0.13	2.87
118-160	3.12	0.23	2.33	0.16	0.74	0.88	0.05	3.22
Pedon AR4; Typic Ustropept								
0-18	5.15	0.41	3.39	0.10	0.35	1.20	0.02	0.85
50-85	1.29	0.41	2.32	0.20	0.47	1.07	0.15	1.15
85-170	0.54	0.23	2.10	0.15	0.56	0.85	0.28	2.43

Table 2 (contd.)

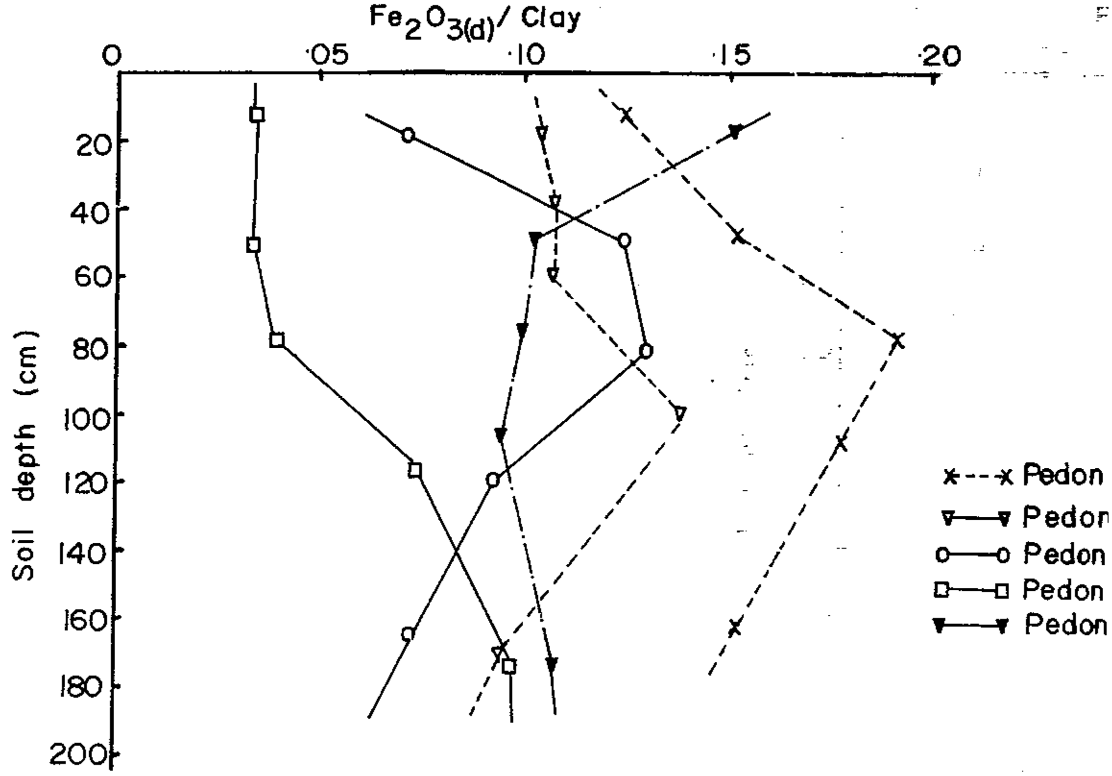
Depth (cm)	DCB extractable Fe_2O_3(d)	Al_2O_3(d)	SiO_2(d)	Oxalate extractable Fe_2O_3(o)	Al_2O_3(o)	SiO_2(o)	$\frac{Fe_2O_3(o)}{Fe_2O_3(d)}$	$\frac{Al_2O_3(o)}{Al_2O_3(d)}$
	%							
Pedon AR5; Albaquic Paleudalf								
0-21	9.46	0.41	5.58	1.05	0.33	1.29	0.11	0.80
40-71	4.80	0.11	3.13	1.25	0.32	0.97	0.26	2.91
110-140	1.23	0.15	1.51	1.03	0.43	0.94	0.84	2.87
Pedon AR6; Kanhaplic Haplustalf								
0-22	6.03	0.49	3.40	0.14	0.16	1.08	0.02	0.33
22-41	12.81	0.45	6.60	0.28	0.12	1.25	0.02	0.27
59-88	7.52	0.41	3.26	0.31	0.23	1.02	0.04	0.56
113-180+	0.86	0.30	3.63	0.12	0.37	1.18	0.14	1.23
Lumda transect								
Pedon LD1; Typic Pellustert								
0-18	2.51	0.45	1.56	0.14	0.42	1.09	0.05	0.93
57-96	2.60	0.45	1.61	0.08	1.02	1.25	0.03	2.27
119-162	1.17	0.23	1.73	0.05	0.84	1.36	0.04	3.65
Pedon LD2; Typic Chromustert								
14-44	2.29	0.38	1.82	0.19	0.26	1.26	0.08	0.68
85-117	2.17	0.34	1.57	0.06	0.69	1.00	0.03	2.03
137-181	1.69	0.26	1.88	0.10	2.01	1.12	0.06	7.73
Pedon LD3; Oxic Ustropept								
0-24	0.89	0.52	1.33	0.08	0.43	1.06	0.09	0.83
56-85	1.80	0.23	1.29	0.15	1.84	0.94	0.08	8.00
115-160	1.74	0.30	1.80	0.10	0.65	1.08	0.06	2.17

$Fe_2O_{3(d)}$ distribution shows an increase with depth whereas the surface horizons of pedon MD1 had more $Fe_2O_{3(d)}$ than its subsoil horizons. The free iron oxide content of the hydromorphic pedons GZ1 to GZ4 was generally low (0.01%)to 0.86%), whereas the upland well-drained pedons GZ5 and GZ6 had relatively high $Fe_2O_{3(d)}$ (0.97% to 10.61%) contents which increased with depth following the pattern of clay distribution. Similar observations had been made on well-drained soils elsewhere (Asamao, 1973; Juo et al., 1974; Okusami et al., 1985; Robertus and Buol, 1985). Soils of Dwam transect contained $Fe_2O_{3(d)}$ ranging between 2.29% and 6.55%. In pedons DM1 and DM2, $Fe_2O_{3(d)}$ content decreases with soil depth. The perched water table resulting from the clayey surface horizons in the two pedons had prevented eluviation of sesquioxides in the pedons. Pedon DM3, however, had erratic pattern of $Fe_2O_{3(d)}$ distribution. All pedons of Argungu transect had free iron distribution similar to the pattern of clay distribution. In pedons AR1 to AR5, the $Fe_2O_{3(d)}$ contents decrease with soil depth. This may be due to reduction processes associated with increasing degree of hydromorphism. However, in pedon AR6, the B horizons contained more $Fe_2O_{3(d)}$ than both the A and C horizons. The oxalate extractable iron, $Fe_2O_{3(o)}$, distribution generally shows a decrease with soil depth (Table 2), except in pedons GZ3, GZ4, AR3, AR4 and the upland pedons MD5, GZ5, GZ6 and AR6.

The amounts of dithionite extractable Al_2O_3 were lower in comparison with those of Fe in all pedons studied except the hydrmorphic pedons GZ1, GZ2, and GZ3 of Gadza transect. The siliceous nature of the dithionite extractable fractions seems to have resulted from rapid desilication due to the tropical climate of the study area. The effects of dry climatic condition on the more siliceous nature of the dithionite-soluble oxides had been reported by Wakatsuki and Wielemaker (1985). The dry climatic condition favours desilication which results in the release of silica into the soil environment during the rainy season. The oxalate extractable Si ($SiO_{2(o)}$) was lower than the dithionite extractable form ($SiO_{2(d)}$) in all horizons of the pedons studied (Table 2). This shows that greater amounts of the silicon were in the more crystalline form.

The distribution of oxalate extractable Fe or Al ($Fe_2O_{3(o)}$ or $Al_2O_{3(o)}$) to dithionite extractable Fe or Al ($Fe_2O_{3(d)}$ or $Al_2O_{3(d)}$) within each pedon can be expressed as active Fe or Al ratio' (Blume and Schwertmann, 1969). These ratios are shown in Table 2. Ratios of active Fe in most of the pedons (except pedons GZ1, GZ2 and GZ3) were low (<0.5), whereas active Al ratios were high (>0.5) in the pedons except pedons GZ5, GZ6 and AR6 which are of course, upland soils. Fey and Le Roux (1977) reported that the acid ammonium oxalate may be the most useful extractant of both amorphous Fe and Al oxides and allophane from sesquioxidic soil clay. Based on this, there was little of amorphous Fe oxides in these soils (except pedons MD1, MD2, MD3, AR1, AR2, and AR5). Active Fe ratios generally decrease with soil depth (Table 2). This indicates that higher proportions of Fe were in more crystalline forms in the lower horizons. Relatively high amounts of active Fe were maintained in some organic-rich horizons (e.g. 0-30cm, 0-22cm, 111-136cm of pedons MD3, MD4 and GZ3 respectively) possibly as organo-Fe complex. Most of the Al in the pedons (except pedons GZ5, GZ6 and AR6) were in oxalate extractable form.

Generally high correlation ($r = 0.46$) exists between $Fe_2O_{3(d)}$ and clay in the pedons studied. Concurrent with increase in clay content is the release of Fe from primary silicate minerals that have weathered to kaolinite and oxide minerals. $Fe_2O_{3(d)}$/clay ratios have been used to measure the extent to which $Fe_2O_{3(d)}$ maxima in B horizons are passive, i.e., result from either in situ clay formation or comigration of $Fe_2O_{3(d)}$ with clay in proportion to clay illuviation (Blume and Schwertmann, 1969). In pedons MD1, MD2, MD3, GZ4, GZ5, GZ6, AR1 and LD2, the $Fe_2O_{3(d)}$/clay ratios were greater in B horizons than in A horizons (Figs 5a, b, c). This indicates some $Fe_2O_{3(d)}$ accumulation independent of clay. It is possible, of course that differences between A and B horizons may be caused by lateral movement of Fe (Rebertus and Buol, 1985), but because



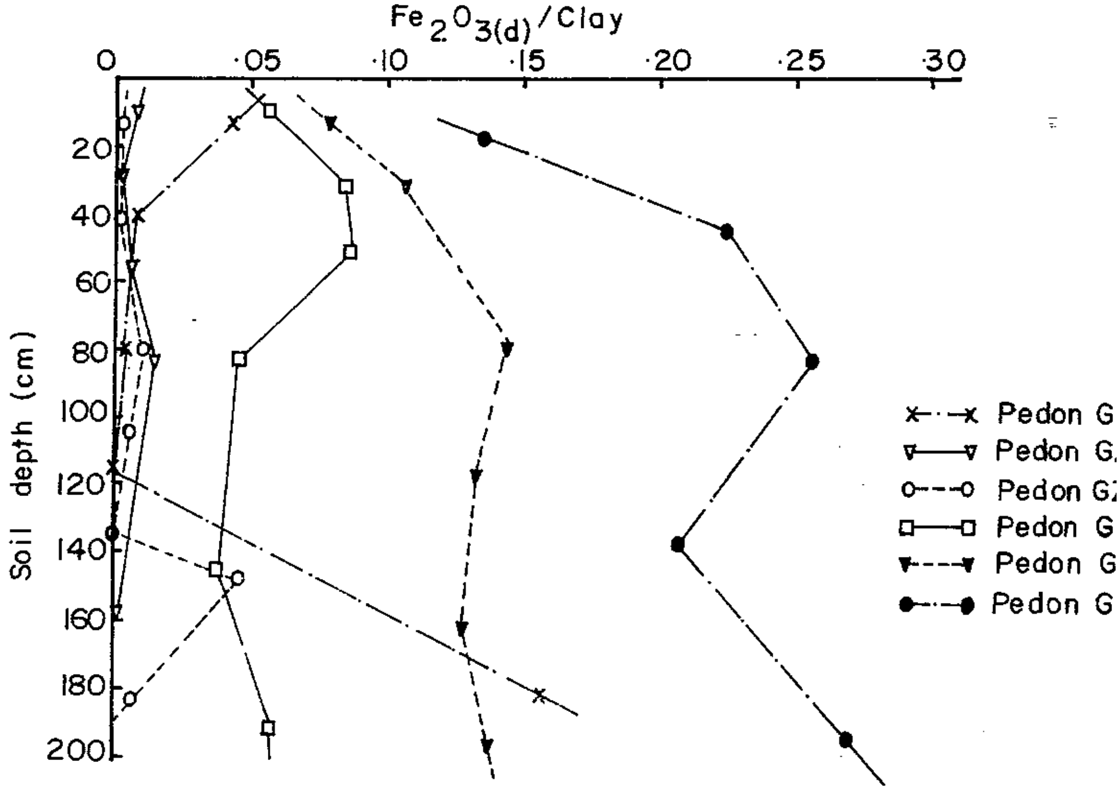
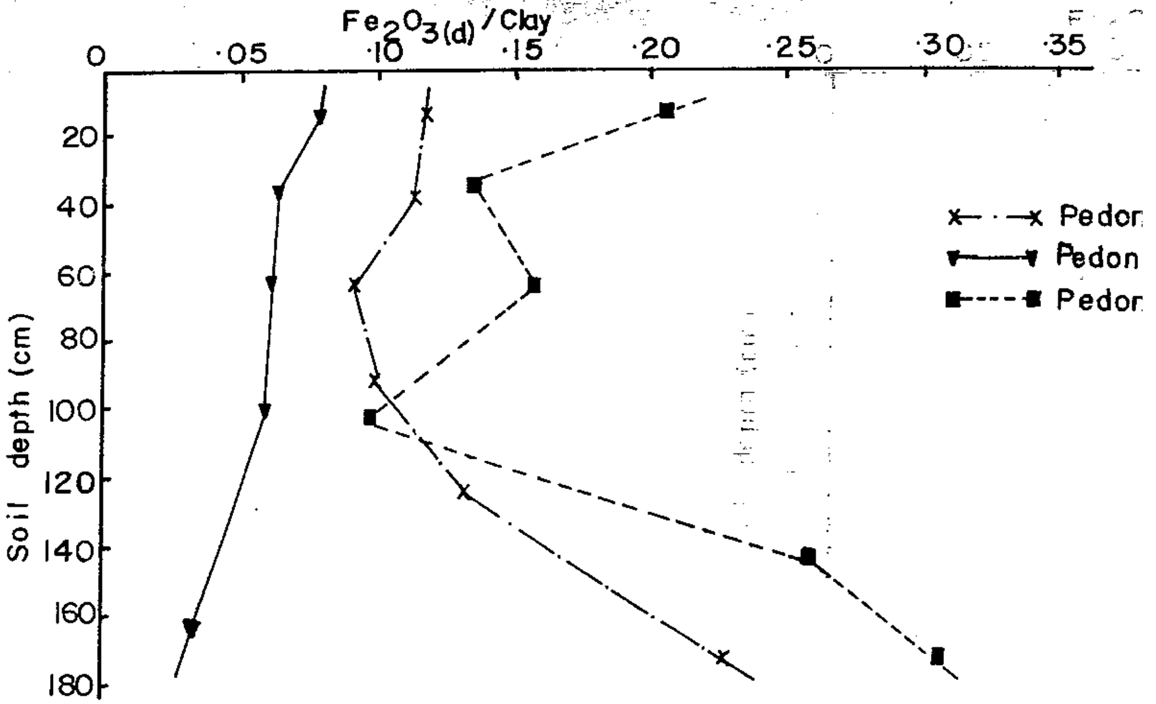


Fig.5a. Dithionite Fe/clay ratio of pedons on Makurdi (MD) and Gadza (GZ) transects.



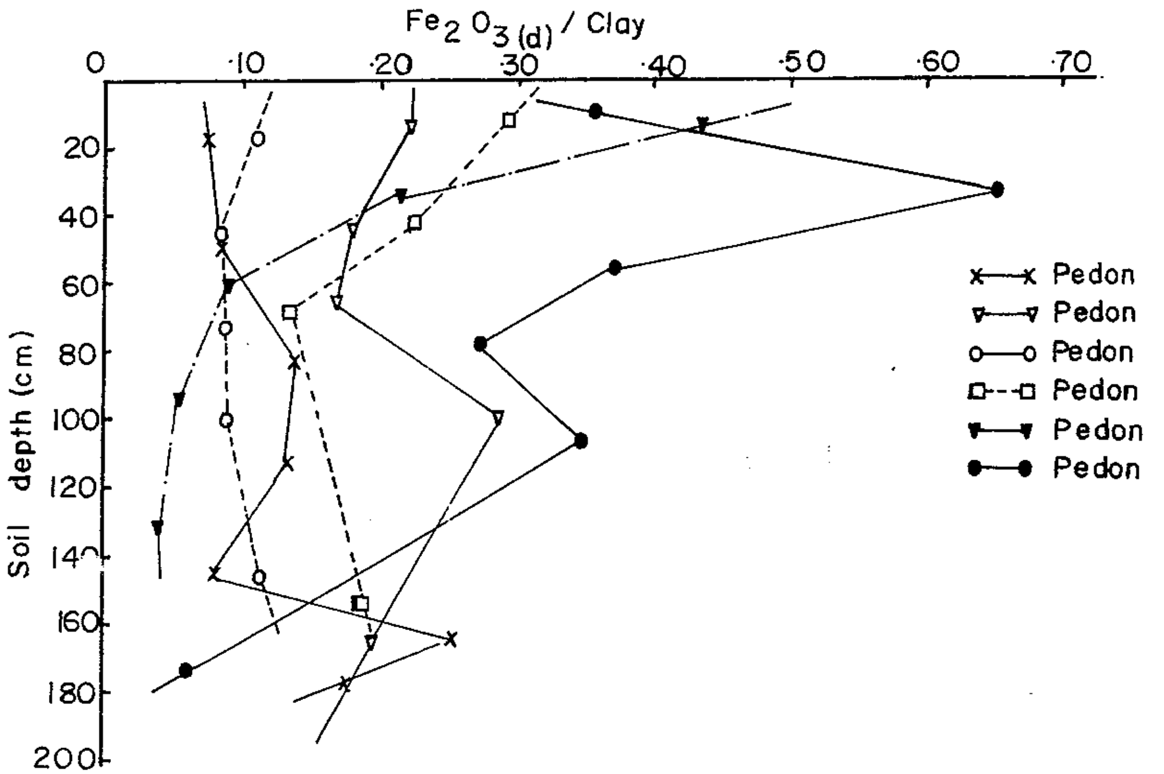


Fig.5b: Dithionite Fe / clay ratio of pedons on Dwam (DM) and Argungu (AR) transects.

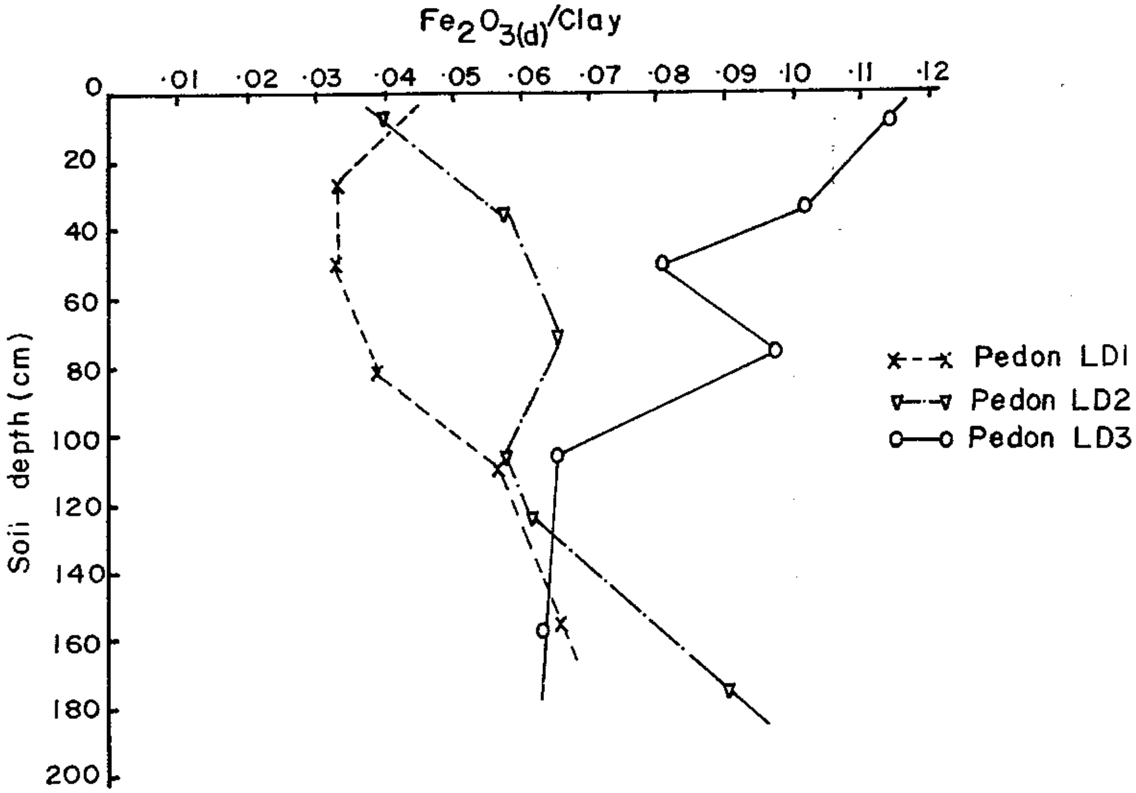


Fig.5 c : Dithionite Fe/clay ratio of pedons on Lumda (LD) transect .

the differences show no systematic trend with either degree of profile development, or slope and landscape position (Figs 5a, b, c), the higher ratios in B horizons most likely indicate independent $Fe_2O_{3(d)}$ migration. When the $Fe_2O_{3(d)}$/clay ratio is fairly uniform with soil deth (typified in pedons GZ2, GZ3, DM2 and AR3; Figs 5a and b), it is believed to indicate a comigration or parallel eluviation of iron and clay (Blume and Schwertmann, 1969). In pedons MD2, GZ2, DM2, AR5, AR6, and LD3 the C horizon ratios were lower than both B and A horizons ratios. This reflects low degree of primary mineral alteration. Extremely high C horizon ratios in pedons GZ1, GZ6, DM1, DM3 and LD2 (Figs 5a and b) reflects alteration of primary minerals in saprolite and low amount of 'in situ' clay formation. Generally, the upland pedons GZ5 and GZ6 had higher ratios than the other pedons of Gadza transect which are hydromorphic.

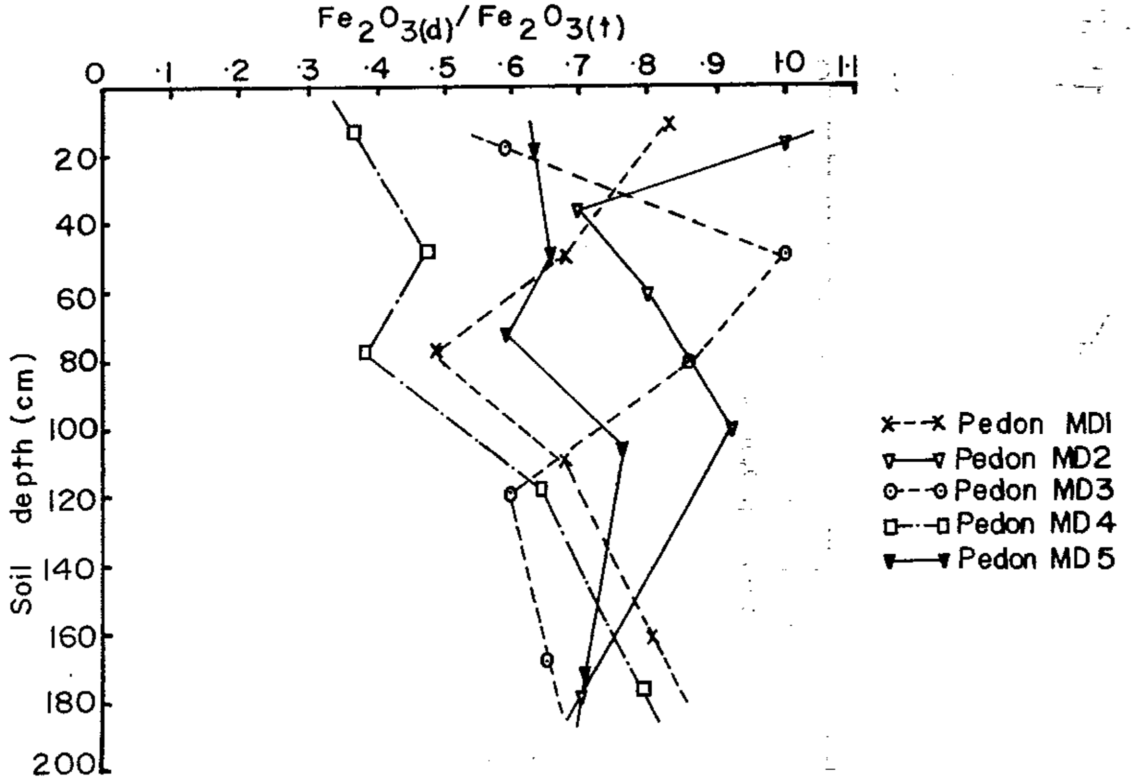
Total free iron oxide ($Fe_2O_{3(d)}$ has been used as an index of determining relative ages of soils (Birkeland _et al_; 1980), mostly in Quarternnary sediments.

Its accumulation in well-drained soils has been associated with lessivage (Asamao, 1973). In the hydromorphic soils, however, a zone of Fe accumulation is due to fluctuations in water table. Pedons GZ1, GZ2, GZ3 and GZ4 owe their hydromorphism mainly to high groundwater tables whereas pedons MD2, MD3, MD4, DM1, AR3 and AR5 had perched water tables. The zone of greatest Fe accumulation may indicate the zone of fluctuating water table (Okusami et al, 1987). This relationship was not very clear for pedons GZ1, GZ2 and GZ3 probably because of their youthfulness and the very few weatherable secondary minerals that could release Fe to the soil environment. The very high active iron ratios (> 0.5) of these soils attests to their youthfulness (Blume and Schwertmann, 1969).

Silica-sesquioxide ratios defined as the molar ratios of SiO_2 (silica) to $Al_2O_3 + Fe_2O_3$ (sesquioxide or R_2O_3), and SiO_2 to $Al_2O_3 + Fe_2O_3$ (sesquioxide or R_2O_3), and SiO_2 to Al_2O_3 (alumina), were believed to afford a method not only for mineral identification, but also for indicating degree of weathering, and relative translocation of soil constituents in the pedon

(Birkeland, 1974). The molar ratios of the dithionite extractable $Fe_2O_{3(d)}$, $Al_2O_{3(d)}$ and $SiO_{2(d)}$ are shown in Appendix E. Decreasing $SiO_{2(d)}/R_2O_{3(d)}$ and $SiO_{2(d)}/Al_2O_{3(d)}$ ratios with soil depth as typified in pedons MD4 and GZ1 respectively could be indicative of movement of Al and Fe. On the other hand, when these ratios increase with soil depth (e.g. pedon DM2) it could be interpreted as movement of Si to deeper depth in the pedon. An almost linear relationship exists between decrease in molar $SiO_{2(d)}/R_2O_{3(d)}$ ratio and percent increase in clay to about 100cm depth in pedons GZ5 and GZ6. This, and presence of clay argillans in Bt horizons in these pedons are due to lessivage of clay.

Results of total elemental analysis shows the predominance of $SiO_{2(t)}$, followed by $Al_2O_{3(t)}$ (Appendix F). Total Fe_2O_3 came next to $Al_2O_{3(t)}$ in terms of abundance in these soils. The siliceous nature of the parent materials coupled with the high temperature of the study area which favours rapid desilication were responsible for the high silica contents. The results indicate the dominance of silicate clay minerals over oxide minerals. Ratios of $Fe_2O_{3(d)}/Fe_2O_{3(t)}$ would reflect the degree of alteration of Fe-bearing primary minerals and the degree of Fe accumulation in illuvial horizons. When plotted against soil depth, the ratio increased nearly systematically for B horizons (Figs 6a, b, c) whereas for A and C horizons it increased somewhat erratically. Pedons of Makurdi transect (except pedon MD3) had similar ratios with depth (Fig. 6a). In Gadza transect, pedons GZ5 and GZ6 had clearly higher ratios than others. Since pedons GZ5 and GZ6 are the only pedons formed in colluvium, the higher ratios were likely the result of a longer time of exposure to weathering due to down-slope entrainment of soil materials as postulated by Rebertus and Buol (1985). Pedons DM1, and AR1 to AR5 had $Fe_2O_{3(d)}/Fe_2O_{3(t)}$ ratios decreasing with soil depth. In pedon AR6, the ratio was higher in B horizon than in both A and C horizons. Similarly, pedons LD2 and LD3 had higher ratios in B horizons than in both A and C



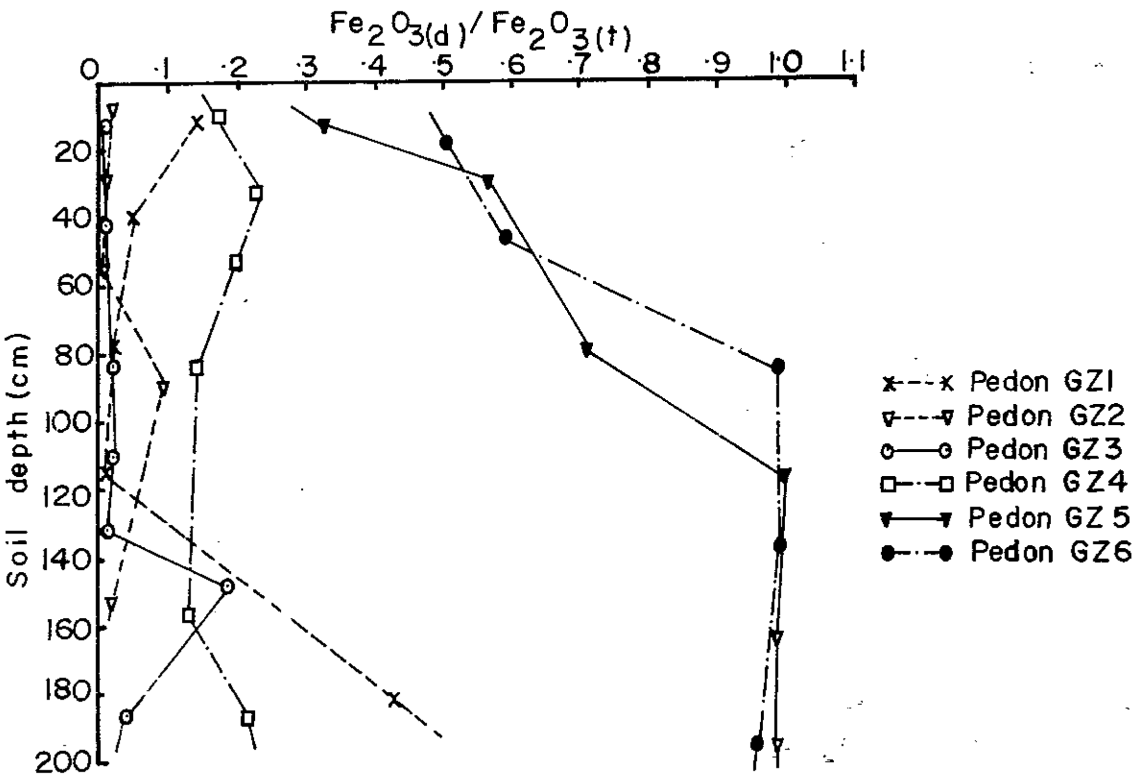
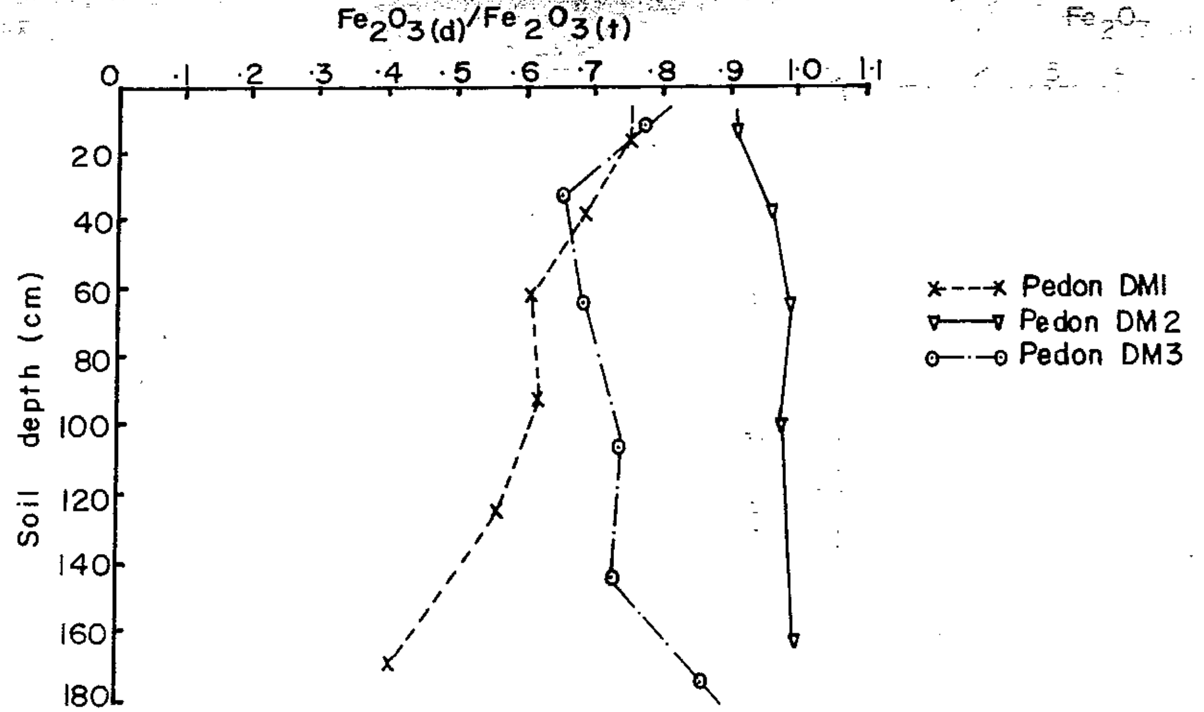


Fig. 6a: Dithionite Fe/total Fe ratio of pedons on Makurdi (MD) and Gadza (GZ) transects.



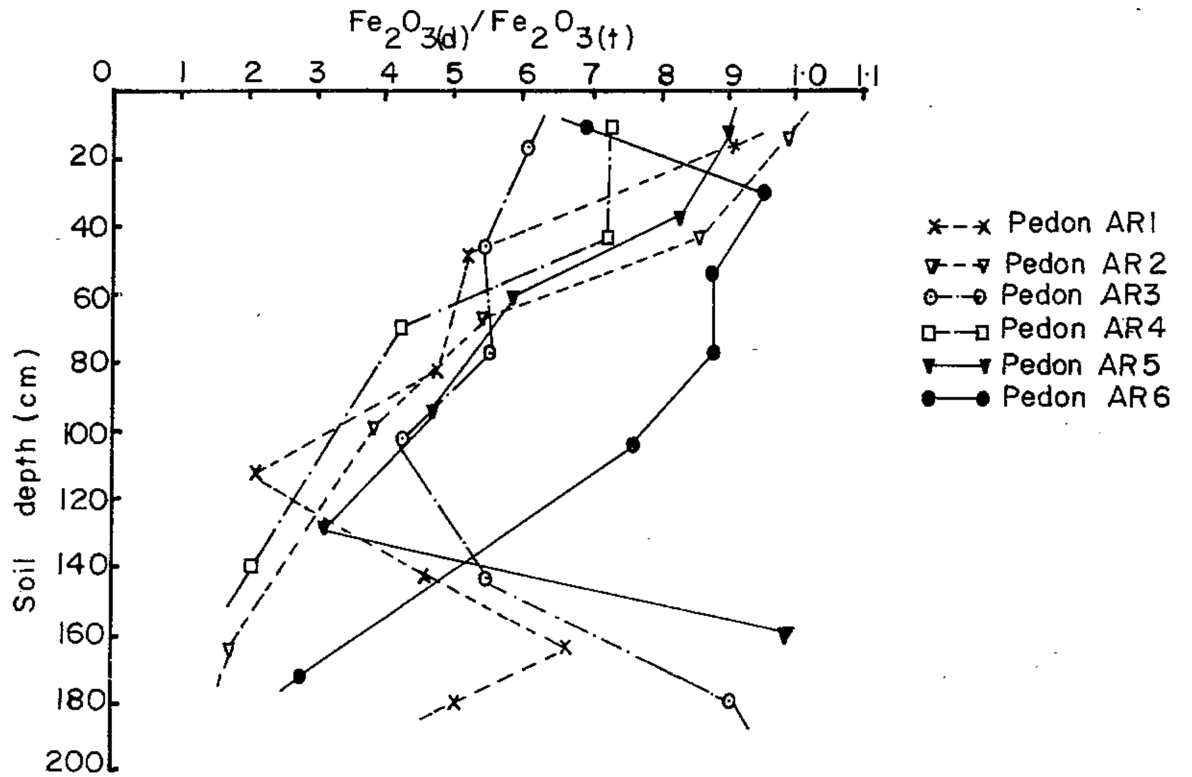


Fig. 6 b : Dithionite Fe / total Fe ratio of pedons on Dwam (DM) and Argungu (AR) transects.

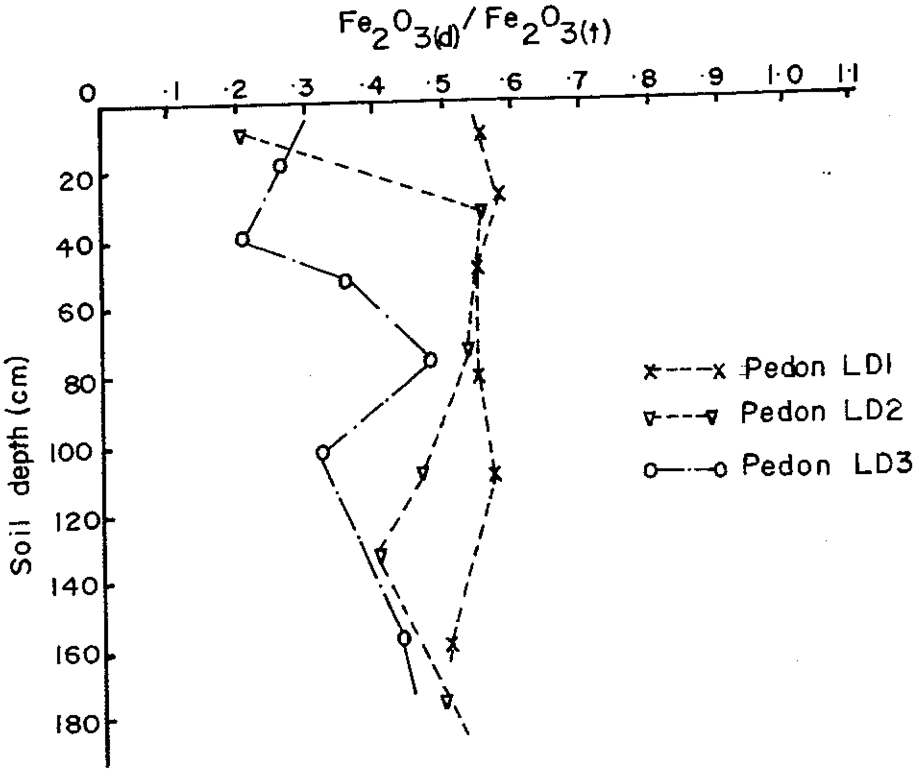


Fig.6c: Dithionite Fe/total Fe ratio of pedons on Lumda transect.

horizons. However, the ratios in pedons DM2 and LD1 appear uniform with depth, which implies that no significant eluviation of Fe had taken place.

In pedons MD2, MD3, DM2, AR1, AR2, AR5 and AR6, the $Fe_2O_{3(d)}/Fe_2O_{3(t)}$ ratios approached and reached 1.0 at A horizons (Figs. 6a and b). Although it might be predicted that A horizons will have lower ratios than B horizons due to $Fe_2O_{3(d)}$ eluviation, the reason for high ratio is probably because maximum silicate weathering in these soils occurred in A horizons and decreased with soil depth. In pedons GZ5, GZ6, LD1 and LD2, the B horizon $Fe_2O_{3(d)}/Fe_2O_{3(t)}$ ratios reached 1.0. The sand content of A horizons combined with loss of $Fe_2O_{3(d)}$ by eluviation could explain why $Fe_2O_{3(d)}/Fe_2O_{3(t)}$ ratios were $<$ 1.0 in A horizons while B horizon ratios reached 1.0. The low C horizon ratios observed in most of the pedons may be because of more iron in silicate structure (silicate weathering decreasing with depth).

5.1.3 Soil mineralogy:

Results of the fine sand fraction (0.225-0.075mm) mineralogical analysis are shown in Table 3. Petrographic studies revealed that quartz comprises 82 to 96 percent of the minerals counted in the fine sand fraction of the soils. Other minerals counted in small amounts were muscovite (especially in pedons of Makurdi and Gadza transects) and feldspars. Heavy minerals (zircon and biotite) of specific gravity greater than 2.89 constituted only a very small percentage and increased with depth in the upland pedons MD5, GZ5, GZ6 and DM3 (Table 3).

Most of the fine sand grains of the hydromorphic pedons were colourless to light gray. Prolonged water saturation in the pedons has led to loss of Fe from the soil, and the grains assumed the light gray colour of the dominant sand-size mineral (quartz). The dominant grain colour of the well-drained pedons (e.g. pedon GZ6) progressively changed from brown to yellowish red in the saprolitic horizons. Under plane-polorized light, grain opacity increased progressively with soil depth

Table 3: Mineral compostion of the fine sand fraction (.225-.075mm) of the pedons

Horizon	Depth (cm)	Quartz	Muscovite	Feldspar	Zircon	Biotite	Opaque
		%					
Makurdi transect							
Pedon MD1; Typic Ustifluvent							
A2	24-59	90	4	4	2	-	-
$2BA_1$	59-87	92	3	-	5	-	-
2BC	120-168	90	5	-	5	-	-
Pedon MD2; Typic Udifluvent							
A	0-25	90	5	-	5	-	-
Bw_1	60-97	86	8	2	4	-	-
BC	130-171	85	6	-	6	3	-
Pedon MD3; Andaqueptic Fluvaquent							
A	0-30	93	-	-	7	-	-
$2Bw_2$	70-113	82	6	6	2	4	-
$2BC_g$	113-182	90	5	-	5	-	-
Pedon MD4; Aquic Kandiustult							
A	0-22	93	-	3	4	-	-
Bwc_1	64-90	93	2	2	3	-	-
BC_g	128-185	94	-	3	3	-	-
Pedon MD5; Typic Kandiustalf							
A	0-26	87	5	5	3	-	-
Bt_1	59-80	84	4	2	5	3	2
C	124-185	82	3	3	6	4	2
Gadza transect							
Pedon GZ1; Typic Tropaquept							
A	0-21	92	2	4	2	-	-
Bw	52-95	90	4	3	3	-	-
C_g	129-192	94	3	-	3	-	-

Table 3 contd.

Horizon	Depth (cm)	Quartz	Muscovite	Feldspar	Zircon	Biotite	Opaque
				%			
Pedon GZ2; Typic Tropaquept							
AB_1	11-32	86	6	-	4	4	-
2BA	60-110	87	6	3	2	2	-
$2C_g$	110-168	90	5	-	3	2	-
Pedon GZ3; Typic Tropaquept							
AB_1	18-55	92	3	-	5	-	-
$2BA_1$	96-111	82	5	2	5	3	3
2C	151-192	92	4	-	4	-	-
Pedon GZ4 ; Aquic Quartzipsamment							
AB_1	20-40	90	-	4	6	-	-
BA	60-93	93	-	-	4	-	3
$BCrg_2$	169-192	96	-	-	4	-	-
Pedon GZ5 ; Typic Kandiustult							
AB	14-37	84	5	3	5	-	3
$2Bt_1$	92-140	82	4	-	3	5	6
2C	182-207	86	2	-	3	6	3
Pedon GZ6; Typic Kandiustult							
A	0-24	87	-	5	5	-	3
$2Bt_1$	59-97	82	6	-	3	5	4
2C	160-200	84	6	-	2	6	2
Dwam.transect							
Pedon DM1; Tropaquent							
A	0-25	86	8	2	4	-	-
$2Bwc_2$	72-103	89	-	-	5	4	2
2C	135-179	86	4	6	-	-	4
Pedon DM2; Udic Chromustert							
A	0-20	84	-	5	7	-	4
Bw_1	42-74	82	-	6	7	-	5
BC	109-165	84	-	8	5	-	3

Table 3 (contd.)

Horizon	Depth (cm)	Quartz	Muscovite	Feldspar	Zircon	Biotite	Opaque
		%					
Pedon DM3; Typic Kandiustalf							
A	0-18	88	-	6	3	-	-
Bt_1	43-76	84	4	5	4 4	-	3
2C	120-160	82	4	6	6	-	2
Argungu transect							
Pedon AR1; Andaqueptic Fluvaquent							
A	0-35	92	-	4	4	-	-
$2AB_2$	61-101	86	-	8	3	3	-
$2BCg_2$	173+	90	-	5	3	2	-
Pedon AR2; Andaqueptic Fluvaquent							
A	0-24	84	4	8	4	-	-
$2Bw_2$	50-77	82	5	4	7	2	-
$2BC_2$	110-179	84	-	8	8	-	-
Pedon AR3; Tropaquent							
A	0-31	86	3	8	3	-	-
$2Bwcg_2$	85-118	84	-	5	8	-	3
3BC	160-194	86	-	6	3	3	2
Pedon AR4; Typic Ustropept							
A	0-18	90	-	6	4	-	-
Bw	18-50	92	-	4	4	-	-
C	85-170	93	-	-	7	-	-
Pedon AR5; Albaquic Paleudalf							
A	0-21	89	3	5	3	-	-
Bt_2	71-110	82	5	7	3	3	-
$2C_g$	140-165	92	-	4	4	-	-
Pedon AR6; Kanhaplic Haplustalf							
A	0-22	86	-	5	9	-	-
Bt_2	41-59	83	5	5	7	-	-
C	113-180+	86	-	7	7	-	-

Table 3 (contd.)

Horizon	Depth (cm)	Quartz	Muscovite	Feldspar	Zircon	Biotite	Opaque
		%					
Lumda transect							
Pedon LD1; Typic Pellustert							
A	0-18	82	-	10	8	-	-
Bw_2	57-96	82	-	4	10	-	4
2C	119-162	88	4	4	4	-	-
Pedon LD2; Typic Chromustert							
A	0-14	84	-	8	8	-	-
$2Bw_2$	85-117	86	-	4	6	-	4
2C	137-181	88	-	6	6	-	-
Pedon LD3; Oxic Ustropept							
A	0-24	90	-	7	3	-	-
$2Bw_2$	56-85	92	-	8	-	-	-
3CB	115-160	95	-	-	5	-	-

(e.g. pedons GZ4 and DM1). This may be due to the release of Fe during geochemical weathering of biotite and subsequent coating of the grains.

X-ray diffraction of the silt fraction (0.05 - 0.002) powder showed a dominance of quartz, and varying amounts of kaolinite, mica, feldspar and vermiculite (Table 4, Fig 7). The presence of kaolinite could indicate that some transformations of minerals such as mica, chlorite, vermiculite and feldspar had taken place. Results of X-ray analysis of silt fraction corroborates what was obtained in petrographic studies of sand fraction. The other feldspars and mica in silt fraction could be residual from the sand fraction. Appendix I show the distribution of minerals in the clay fraction ($<$0.002mm) of some horizons of the pedons. All pedons studied were characterised by high peaks at 0.721nm, 0.790nm, and 1.000nm (Figs. 8, 9, 10), indicating the presence of kaolinite, metahalloysite, and mica. Kaolinite was the dominant clay mineral in the soils (except in pedons DM2, LD1 and

Table 4: Silt fraction mineralogy of representative pedons

Horizon	Depth (cm)	Quartz	Feldspar	Vermiculite	Kaolinite	Mica
				%		
Pedon MD1; Typic Ustifluvent						
Ap_1	0-24	62.3	8.0	-	13.9	15.8
$2BA_1$	59-87	65.5	5.8	-	11.6	17.1
2BC	120-168	69.0	-	-	10.8	20.2
Pedon MD3; Andaqueptic Fluvaquent						
A	0-30	59.4	-	-	21.9	18.7
$2Bw_2$	70-113	60.2	-	-	28.2	11.6
$2BC_g$	113-182	58.8	2.1	-	21.0	18.1
Pedon MD5; Typic Kandiustalf						
A	0-26	53.4	9.5	-	18.4	18.7
Bt_1	59-80	53.6	4.2	-	21.0	21.2
C	124-185	48.5	7.3	-	24.4	19.8
Pedon GZ1; Typic Tropaquept						
A	0-21	64.5	-	-	19.6	15.9
Bw	52-95	68.3	-	-	14.8	16.9
C_g	129-129	68.7	-	-	20.7	10.6
Pedon GZ4; Aquic Quartzipsamment						
A_p	0-20	58.5	-	-	23.6	17.9
BA	60-93	59.1	5.3	-	18.8	16.8
$BCrg_2$	169-192	56.6	5.5	-	18.2	19.9
Pedon GZ5; Typic Kandiustult						
A	0-14	43.1	9.9	-	26.2	20.8
$2Bt_1$	92-140	50.2	8.6	-	24.9	16.3
2C	182-207	51.9	10.2	-	17.0	20.9

Table 4 (contd.)

Horizon	Depth (cm)	Quartz	Feldspar	Vermiculite	Kaolinite	Mica
		%				
Pedon DM1; Tropaquent						
A	0-25	49.3	8.4	9.3	15.5	17.5
Bwc_1	44-72	56.0	5.0	8.6	14.0	16.4
2C	135-179	51.4	7.9	8.8	12.7	19.2
Pedon DM2; Udic Chromustert						
A	0-20	38.4	14.7	-	19.9	27.0
Bw_1	42-74	31.6	17.2	-	18.1	33.1
BC	109-165	25.3	24.0	-	10.3	40.4
Pedon AR4; Typic Ustropept						
A	0-18	64.6	-	-	14.9	20.5
BC	50-85	63.5	5.5	-	8.2	22.8
Pedon AR5; Albaquic Paleudalf						
A	0-21	56.5	-	4.2	16.4	22.9
Bt_1	40-71	56.0	3.8	6.0	10.6	23.6
$2C_g$	140-165	58.3	-	3.5	8.0	30.2
Pedon AR6; Kanhaplic Haplustalf						
A	0-22	52.3	8.6	-	18.6	20.5
Bt_1	41-59	54.1	9.6	-	19.0	17.8
C	113-180+	57.7	11.8	-	9.9	20.6
Pedon LD1; Typic Pellustert						
A	0-18	35.9	11.1	8.0	24.8	20.2
Bw_2	57-96	31.6	21.4	13.6	21.5	23.1
2C	119-162	29.3	16.2	15.0	14.1	25.4

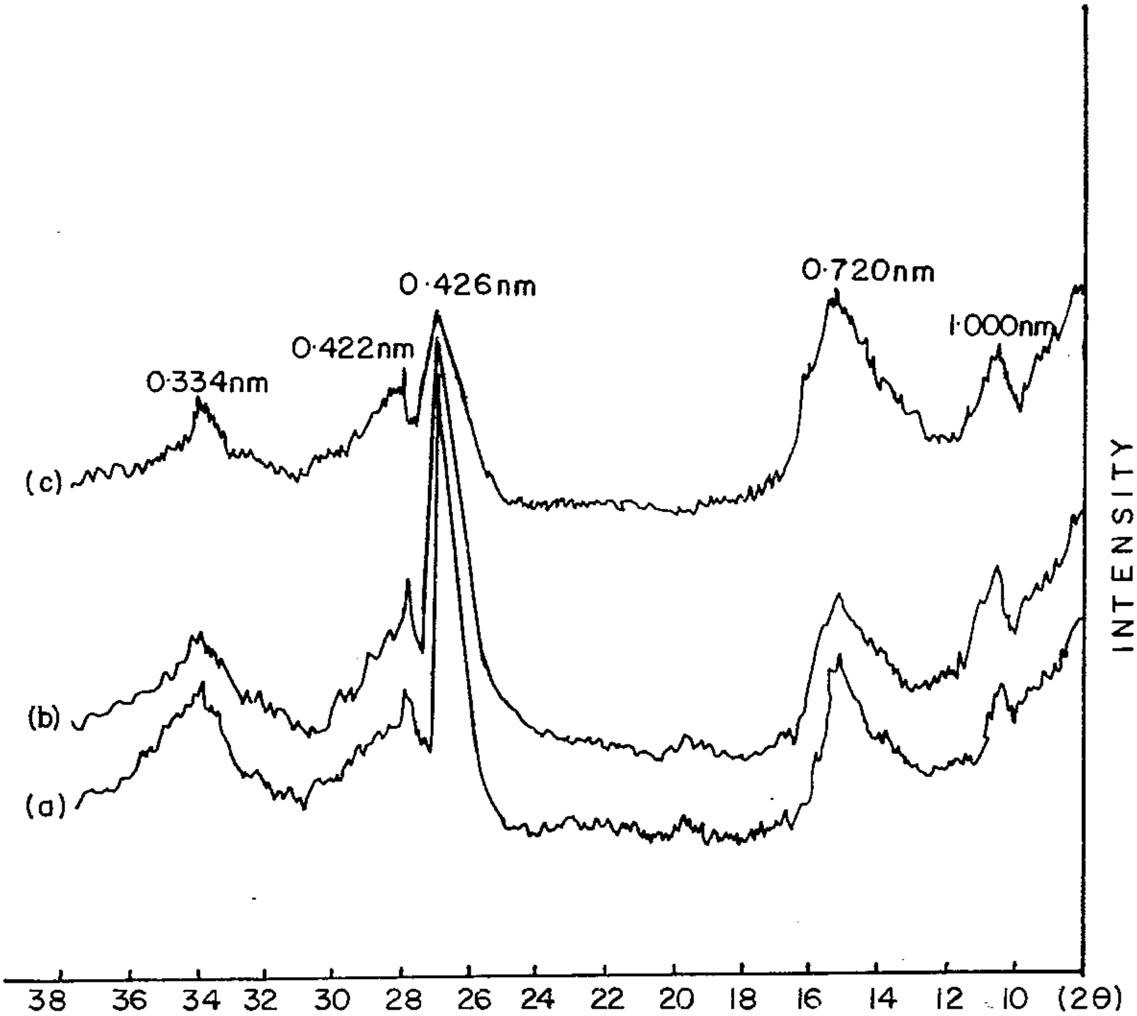


Fig. 7 : X-ray diffractograms of pedon GZ6 silt fraction

(a)= A horizon(0—24cm depth); (b) = 2Bt$_1$ horizon (59—97cm depth) ; (c)= 2C horizon (160 — 200 cm depth).

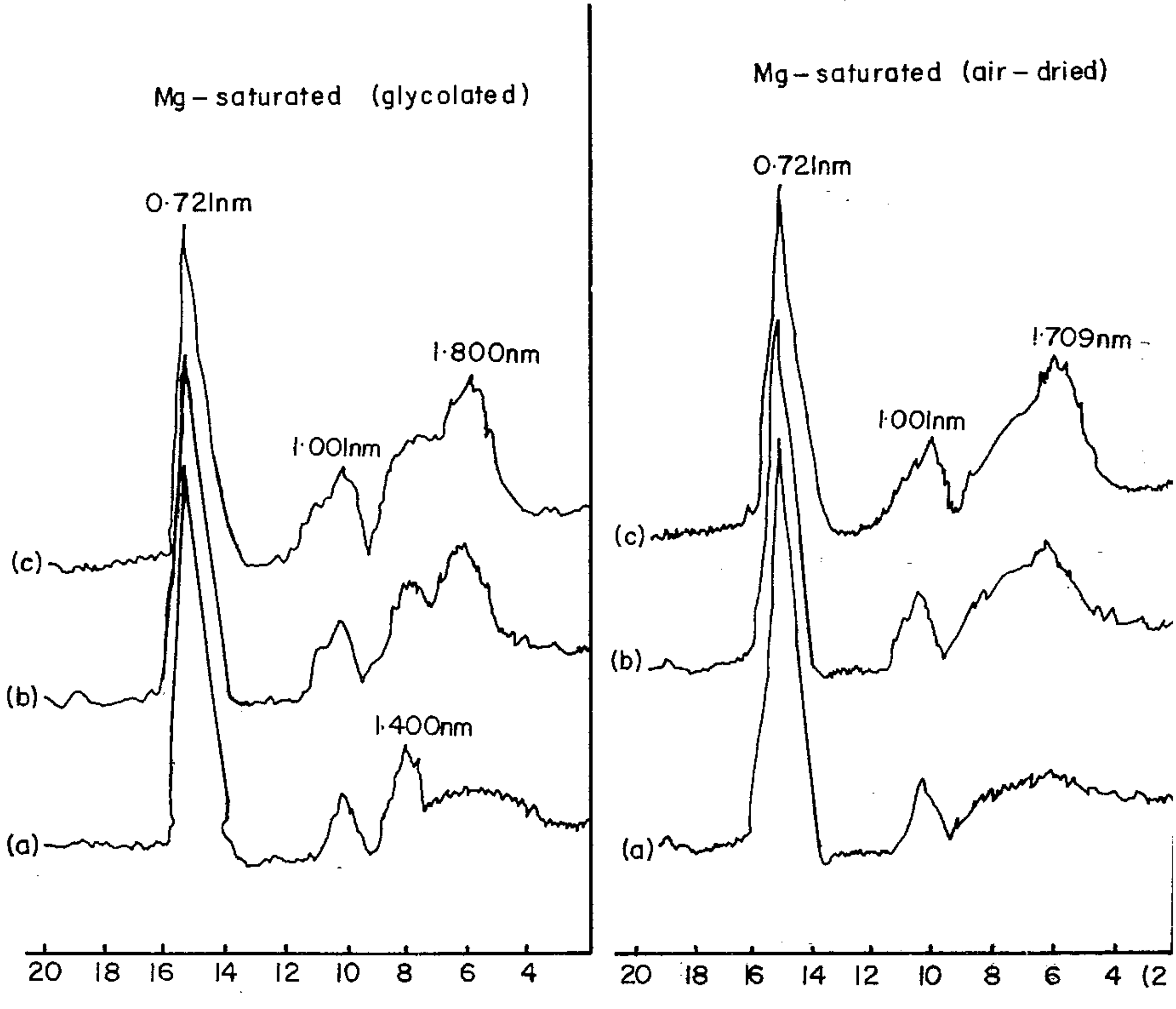


Fig. 8 : X – ray diffractograms of pedon MD3 clay fraction [Mg saturated ; air – dried and glycolated].

(a) = A (0 – 30 cm depth); (b) = $2Bw_2$ (70 – 113 cm depth) ; (c) = 2BCg (113 – 182 cm depth)

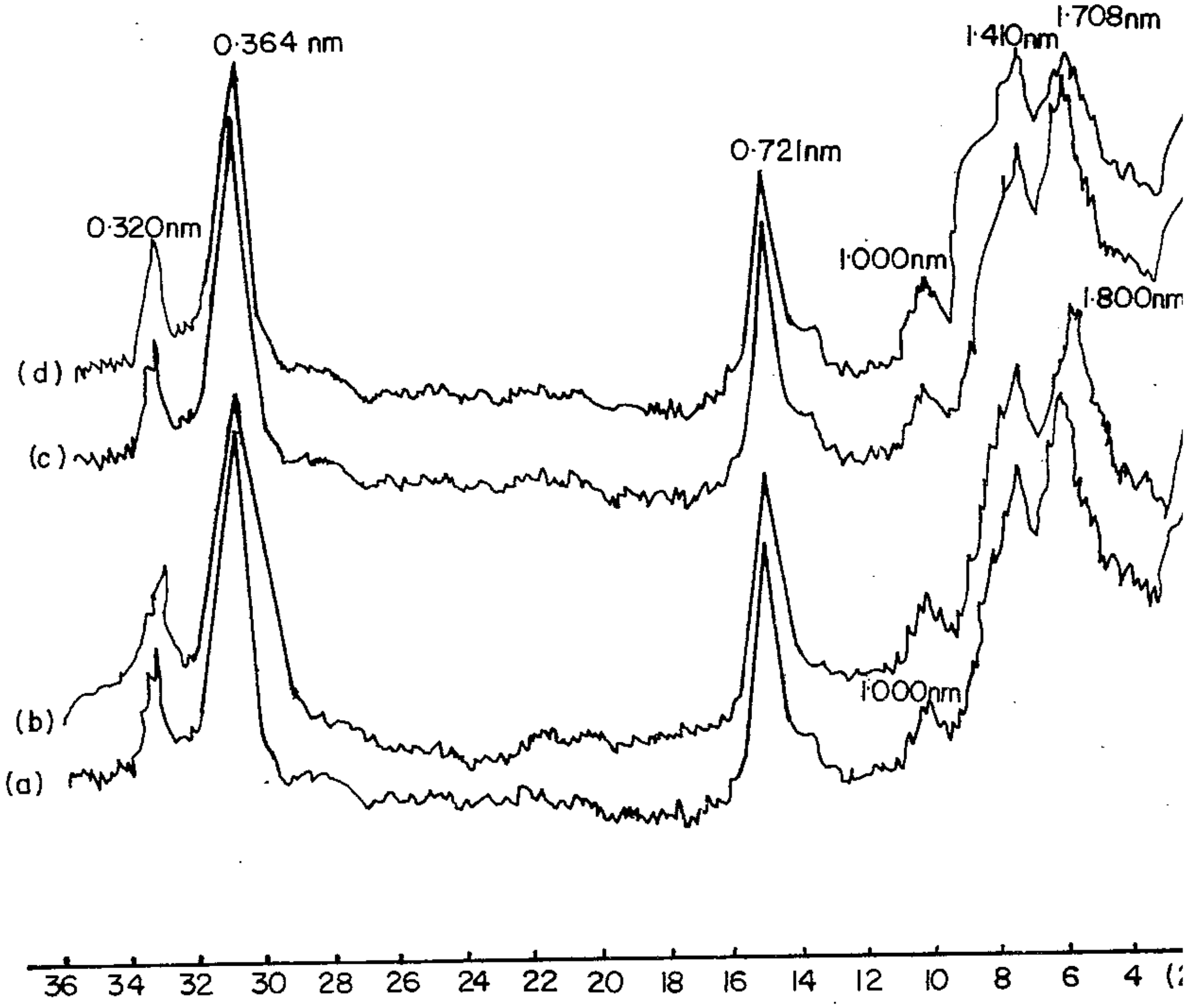


Fig. 9 : X-ray diffractograms of pedon LD1 (57–96cm depth) clay fracti
(a)=Mg-saturated (air dried); (b) = Mg-saturated (glycolated);
(c)=K-saturated (air dried); (d) = K-saturated (110°C heating).

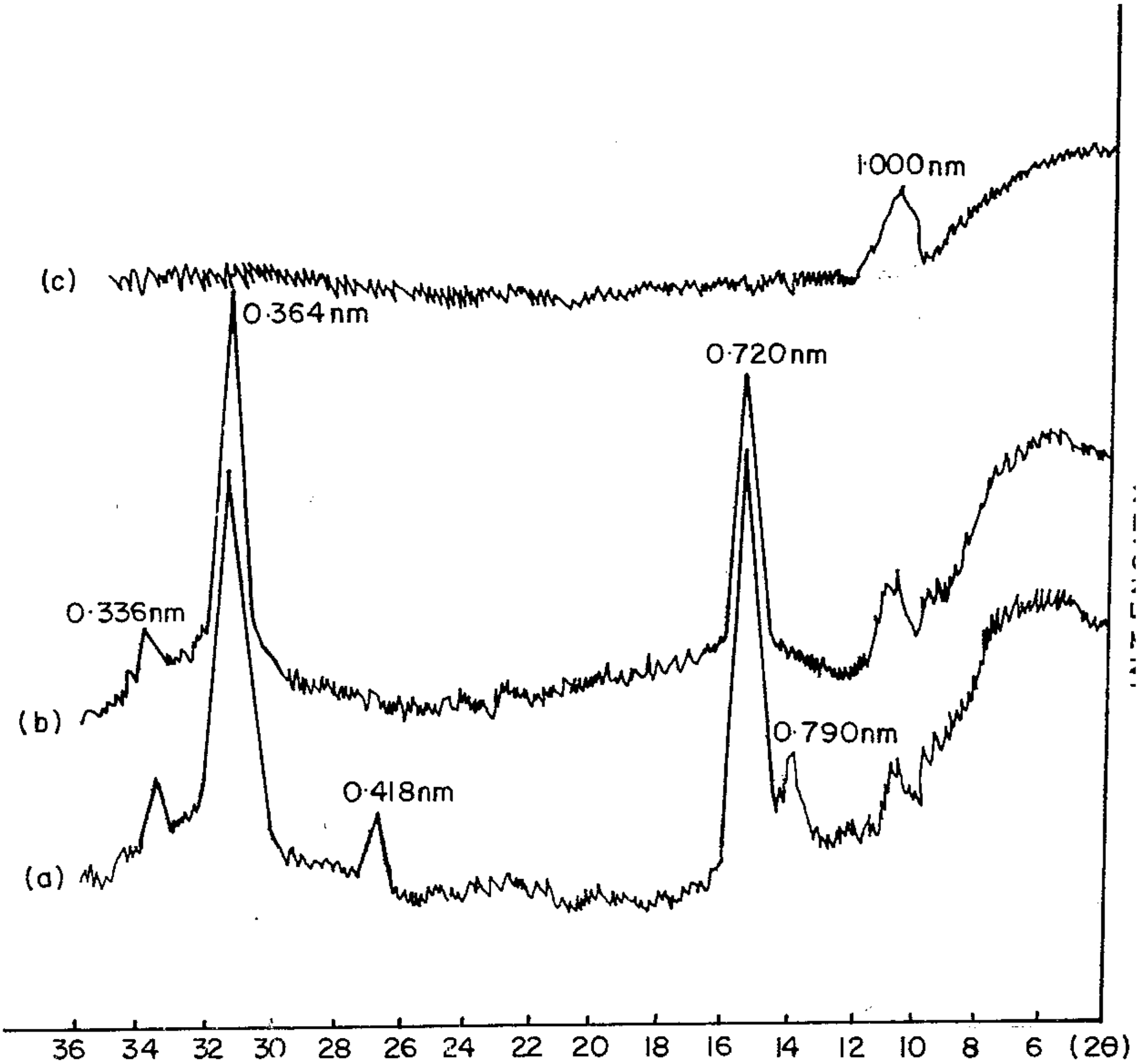


Fig. 10 : X-ray diffractograms of pedon AR 5 (40-71 cm depth) clay fraction

(a) = K-saturated (air dried); (b) = K-saturated (300°C heating);

(c) = K-saturated (550°C heating).

LD2 which contained smectitic clays).

Horizons of pedon DM1, and AR1 to AR5 are formed in low exchange capacity matrix of kaolinite, plagioclase, quartz and muscovite (Table 5). The well - drained upland pedons MD5, GZ5, GZ6, and AR6 (Table 5) contained some hematitie and goethite in addition to kaolinite, metahalloysite, mica and quartz. Pedons DM2, LD1 and LD2 are principally formed in shaly parent materials and contained predominantly smectite clay minerals, but weathering is increasingly changing this to chlorite and kaolinite (Fig. 9). Eluviation of bases, silica and alumina from high topographic sites into the lowlands has been a continuous process. Accumulation of these materials in the soil environment probably gave rise to the detected smectite in pedon AR5 (Fig. 10).

The 0.721nm diffraction peak obtained in K-saturated sample disappeared when the sample was heated at 550°C (Fig 10) indicating a destruction of kaolinite at this tmperature (Whittig, 1965). The metahalloysite peak (0.790nm) was also destroyed by

Table 5: Clay fraction (<0.002mm) mineral composition of representative pedons

Depth (cm)	kaolinite	metahalloysite	mica	smectite	chlorite	vermiculite	feldspar	quartz	hematite	goethi
	%									
Pedon MD5; Typic Kandiustalf										
0-26	62.9	20.4	16.7	-	-	-	-	-	-	-
59-80	58.3	8.8	4.9	-	-	-	-	-	16.4	11.6
124-185	59.8	4.9	3.0	-	-	-	3.8	-	13.8	14.7
Pedon GZ5; Typic Kandiustult										
0-14	54.5	18.2	17.5	-	-	-	-	9.8	-	-
92-140	49.0	15.0	10.9	-	-	-	-	5.5	16.7	3.0
182-207	39.2	10.4	19.4	-	-	-	-	8.5	11.9	10.6
Pedon DM1; Tropaquent										
0-25	49.4	-	20.3	-	-	19.6	10.7	-	-	-
44-72	47.5	-	22.4	-	-	18.8	11.3	-	-	-
135-179	50.9	-	17.6	-	-	20.3	11.2	-	-	-
Pedon AR1; Andaqueptic Fluvaquent										
0-35	60.8	9.1	8.3	-	-	-	13.8	8.0	-	-
61-101	61.0	11.9	8.5	-	-	-	11.3	7.3	-	-
157-173	56.1	19.3	6.2	-	-	-	10.4	8.0	-	-
Pedon AR3; Tropaquent										
0-31	69.3	-	14.6	-	-	-	16.1	-	-	-
58-85	65.1	5.0	9.8	-	-	-	20.1	-	-	-
118-160	66.0	-	21.8	-	-	-	12.2	-	-	-
Pedon AR4; Typic Ustropept										
0-18	61.1	7.2	9.5	-	-	-	12.0	10.2	-	-
50-85	59.3	10.0	8.3	-	-	-	11.1	11.3	-	-
Pedon AR5; Albaquic Paleudalf										
0-21	56.3	-	5.2	-	-	14.4	13.0	11.1	-	-
40-71	29.1	1.6	2.5	22.2	-	13.5	27.4	3.0	-	-
140-165	28.6	1.0	3.8	28.4	-	-	27.9	3.4	-	6.9

Table 5 (contd.)

Depth (cm)	kaolinite	metahalloysite	mica	smectite	chlorite	vermiculite	feldspar	quartz	hematite	goeth
	%									
Pedon AR6; Kanhaplic Haplustalf										
0-22	61.7	11.3	8.7	-	-	-	18.3	-	-	-
41-59	48.5	6.9	8.9	-	-	-	18.0	3.6	-	14.1
113-180+	39.6	15.9	4.7	-	-	-	17.3	1.0	7.0	12.5
Pedon LD2; Typic Chromustert										
0 - 14	13.9	-	6.2	36.1	28.3	-	15.5	-	-	-
44 - 85	16.3	2.0	3.2	37.3	28.1	-	13.1	-	-	-
137-181	19.0	1.0	3.4	32.3	28.1	-	11.0	5.2	-	-

heating at 550°C whereas the 1.000nm diffraction peak characteristic of hydrous mica was enhanced when heated at 550°C (Fig. 10).

Heating of K-saturated clays at 110°C increased the intensity of the 1.000nm peak indicating the collapse of smectite (Fig. 6). This treatment also produced a shoulder at 1.270nm (Fig. 10) which indicated the presence of interstratified minerals. This shoulder may be attributed to partial collapse of smectite or chloritized smectite, or both. The 300°C (Fig 10) heat treatment led to complete dehydration of goethite (disappearance of the 0.418nm peak). The 1.000nm peak obtained after 300°C heat treatment in pedon AR5 clay sample may indicate the presence of some interstratified minerals. Smectite-vermiculite interstratification is highly suspected.

The patterns of Mg-saturated (air dried) and Mg-saturated (glycolated) clays indicate that pedons MD3, DM2, AR5, LD1 and LD2 samples contained smectite, chlorite, feldspar, mica and kaolinite. The 1.708nm peak shifted slightly to about 1.800nm upon glycolation (Fig. 6), leaving a small but sharp peak at 1.410nm which indicates the presence of smectite along with chlorite and/or vermiculite, or their intermediate. Formation of vermiculite is favoured by the neutral to alkaline environment and incomplete leaching of exchangeable cations like Ca, Mg, Na and K due to perched water table. Vermiculite can also be an intermediate product in the course of weathering of ferromagnessian minerals. The expansion of smectite was more pronounced in pedons LD1 (Fig. 9) and DM2 (Fig. 11) than in pedons LD2 and AR5 (Fig. 10) as well as in the lower horizons of pedons AR5 and MD3 (Fig. 8).

The intensity of 1.400nm peak which appeared after glycolation decreased with increasing soil depth in pedon MD3 (Fig 5). This might be due to partial chloritization of smectite as a result of incorporation of iron, and possibly to some aluminium interlayers by the mechanism referred to as ferrolysis. The process of partial chloritization implies that

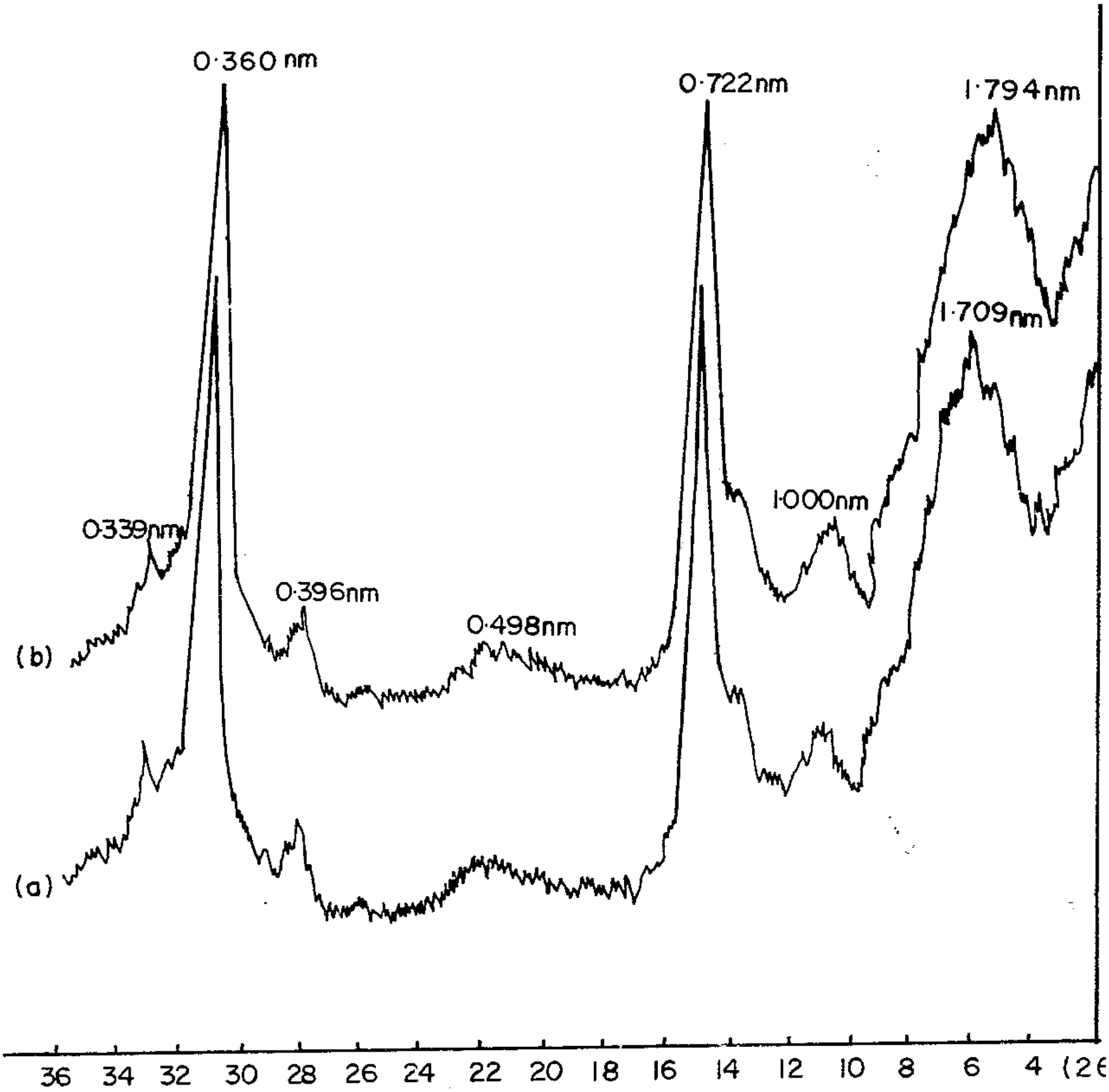


Fig. 11 : X-ray diffractograms of pedon DM2 (42–74 cm depth) clay fract

(a) = Mg-saturated (air dried); (b)= Mg-saturated (glycolated).

exchangeable bases are leached and Al (or Fe) - octahedral sheets are formed at interlayer positions of the smectite, in which a chloritized smectite layer could be considered as equivalent of 2 units of kaolinite layers. This chloritization process can be associated with partial disolution of exchangeable bases (partial decomposition of smectite) as explained by Brinkman, (1978).

The presence of smectite suggests a weathering environment rich in silica such that amorphous clay constituents with low molar ratios of SiO_2 to Al_2O_3 may not form. That the soil environment remains rich in Si and poor in Al (high SiO_2/Al_2O_3 ratio, Appendix E) could be due to the weathering products formed by the parent material. High molar ratio of SiO_2 to R_2O_3 in combination with a high molar ratio of Fe_2O_3 to R_2O_3 suggest that on weathering more Si and Fe oxides than Al oxide are formed. Wada (1982) had reported that Si retards crystallisation of Fe-oxides whereas a high molar ratio of Si to Al favours formation of crystalline layer silicates.

5.2 Soil genesis

5.2.1 Parent material lithology

Morphologic features such as texture and particle size distribution on clay-free basis (Appendix C) were used as indicators of the homogeneity or otherwise of the parent materials. The essence of particle size distribution calculated on clay-free basis is to remove the effect of possible translocated clay (Smith and Wilding, 1972). The fine sand and the very fine sand proportions (Appendix C) were used to indicate lithologic discontinuities within individual pedons because these two size fractions dominate the sand fraction, and are made up of mainly quartz.

There was a significant change in the fine sand size fraction at the 59-to 87-cm horizon of pedon MD1 although the very fine sand would place this a little higher in the pedon. The fine sand distribution in pedon MD2 appears uniform with depth. For pedon MD3, morphologic observations suggest a lithologic break at 45- to 70-cm horizon and this is corroborated by the two size fractions. The clay-free size analysis would not support the idea of multi-parent material sources for pedons MD4 and MD5. The distribution of fime and very find sand fractions in pedon GZ1 appears uniform with depth, thus nullifying the possibility of stratified parent materials. Field morphologic observations and clay-free size analysis suggest a lithologic discontinuity at 60-to 110-cm and 96- to 111cm horizons of pedons GZ2 and GZ3 respectively. Also, sudden shift in texture from sandy loam to sandy clay at 92-to 140-cm and 59- to 97-cm horizons of pedons GZ5 and GZ6 respectively would suggest lithologic discontinuities.

The clay-free size analysis suggests stratified parent materials at 72- to 103-cm and 76- to 120-cm horizons of pedons DM1 and DM3 respectively. However, neither morphologic features nor clay-free size distribution would support the idea of a multi-parent material for pedon DM2. In Argungu transect, both the morphologic features and the clay-free size analysis indicate that pedons AR4 and AR6 were formed in uniform parent materials. Particle size distributions suggest lithologic break at 61- to 101-cm and 50- to 77-cm horizons of pedons AR1 and AR2, whereas the lithologic break in pedon AR5 occured at the saprolitic (140- to 160-cm depth) horizon. Both the fine and the very fine sand size fractions indicate some stratifications at 85- to 118-cm and 118- to 160-cm horizons of pedon AR3.

The fine sand distribution in pedon LD1 indicates a lithologic discontinuity at 96-to 119-cm horizon. Morphologic observations and clay-free size analysis suggest stratified parent materials in pedon LD2 at 14-to 44-cm horizon. The clay-free size analysis indicates multi-parent materials for pedon LD3 at 44-to 56-cm and 115-to 160-cm horizons. The high amounts of heavy minerals (zircon and biotite) observed in pedons DM1, AR2, AR3, and LD1 indicate lithologic discontinuity between the top alluvial/colluvial materials and the underlaining materials.

5.2.2 Dominant soil forming processes.

The particle size distributions of pedons MD1 to MD4 clearly reflect the influence of floodwater flow rate, transportation and deposition of sediments with little pedogenic processes thereafter. Pedon MD1 had sandy texture while pedons MD2, MD3 and MD4 had clayey texture throughout the pedon. Similarly, pedons GZ1 to GZ4 which are under the influence of hydromorphism had no consistent particle size distribution pattern within the pedon. The effect of cumulization (Buol et al., 1980) is clearly shown in pedons MD1 to MD4 and GZ4. Of paramount importance to the identification of argillic horizons, is evidence of illuviation, either as clay films on ped surfaces or as oriented clay in thin section (Soil Survey Staff, 1975). As a result of intense leaching in pedons GZ1 to GZ3, argillic horizon development is retarded. However, the upland pedons MD5, GZ5 and GZ6 had evidence of eluvial/illuvial transportation processes (presence of argillic horizons) and more horizon development.

In pedons DM2, LD1 and LD2, the only noticeable active pedogenic process is soil displacement, as evident by the presence of slickensides. Pedoturbation as a result of such displacement has been sufficient to prevent strong horizon development. Yaalon and Kalmar (1978) proposed what has been termed a 'soil mechanics model', whereby unequal wetting from water penetrating to considerable depth along cracks produces horizontal stress in excess of the shear strength of the soil, resulting in failure planes or slickensides. More recently, Buol et al. (1980) suggested a self swallowing mechanism wherein the surface soil is sloughed off into shrinkage cracks. Upon rewetting, the soil swells but the volume is constrained by the soil in filling the cracks. This results in high pressures, which are relieved by displacing the soil mass to the sides and upwards, forming slickensides, gilgai, and other related features. Absence of micro-relief (gilgai) in the study sites gives credence to the relevance of Yaalon and Kalmar's 'soil mechanics model' to the situations in pedons DM2, LD1 and LD2. Results show that smectite content of B horizons of pedons DM2, LD1 and LD2 is most likely a result of an 'in situ' alteration of plagioclase by hydrothermal processes prior to soil formation. Evidence of illuviation was lacking in the B horizons of these soils, presumably because of disruption of ped surfaces during shrink-swell cycles (Nettleton et al., 1969), extensive desiccation (Buol, 1965) or pedoturbation (Hugie and Passey, 1963). However, pedons DM3, AR5 and AR6 showed evidence of eluvial/illuvial transportation

processes that have resulted in clay accumulation (Fig. 1). In addition to the presence of clay skins, clay accumulation had been sufficiently thick in pedons DM3 and AR6 to qualify as argillic horizons. Particle size distribution of pedons AR1 to AR4 shows that little pedogenic processes had taken place on the soil materials (lack of B horizons with clay accumulation).

Exchange acidity and Al saturation could be useful indices of horizon development of some soils of the tropical region sometimes obscured by subtle differences in morphological features. Generally, Al saturation has been found to be higher in hydromorphic pedons (Ragland and Coleman, 1959). Greater Al saturation in the upper horizons of pedons MD2 and MD5 suggests 'in situ' weathering as horizons of these pedons have been suggested to have formed in homogenous parent materials. Differential accumulation of Al, especially in hydromorphic soils with perched water table (e.g. pedon MD4) may indicate the actively weathering zone of the solum, because exchangeable Al is not considered mobile in the soil (Gotoh, 1976). The presence of relatively high Al saturation (Figs. 12a and b), especially in pedons MD2, GZ2, GZ3 and GZ4 would seem to support the ferrolysis concept of Brinkman (1970) and the hypothesis of Buol et al (1980), who proposed that clay mineral lattice destruction results in the the release of Al ions. The warm soil temperature

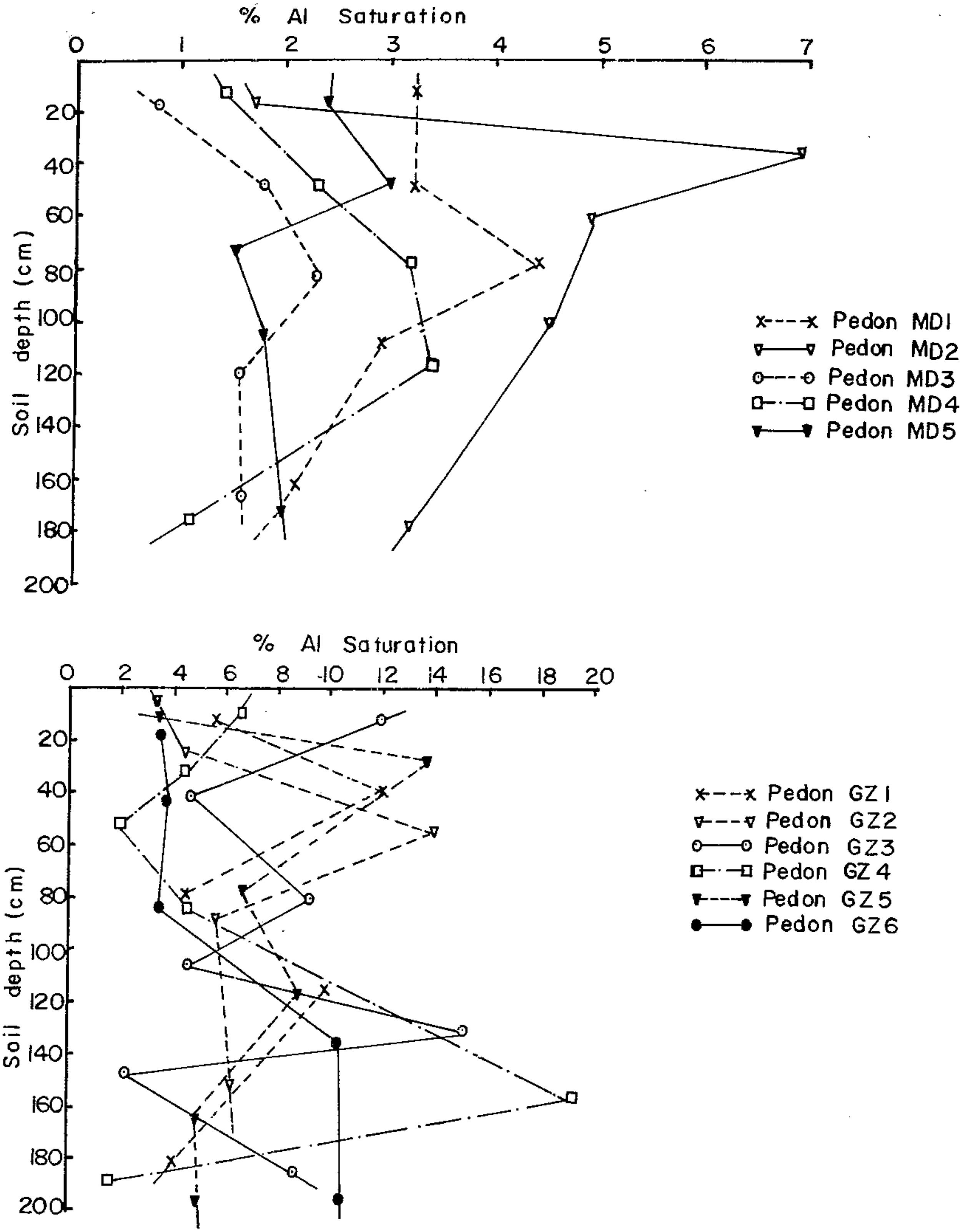


Fig.12a: Percent Al Saturation of the pedons on Makurdi (MD) and Gadza (GZ) transects.

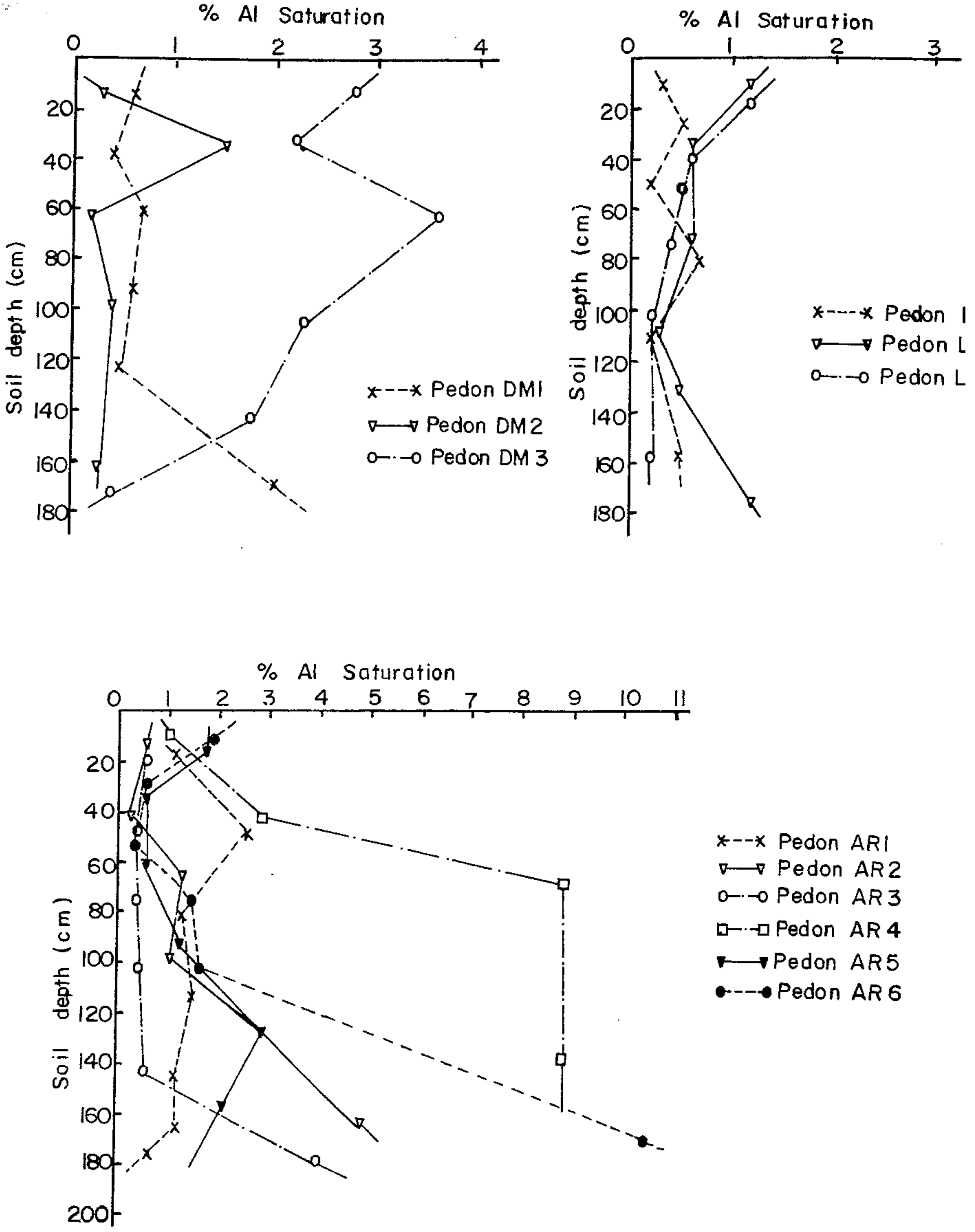


Fig.12b : Percent Al saturation of the pedons on Dwam (DM), Lumda (LD conditions in savanna region of Nigeria are believed to cause the marked dissociation of soil water leading to a build-up of hydrogen ions, which favours hydrolytic or H-weathering of silicates to kaolinite (Ojanuga, 1979). Environmental conditions that favour the crystallization of hematite from Fe released by weathering of primary minerals in the soil environment include high temperature, low moisture and low organic matter content (Kampf and Schwertmann, 1983). The occurrence of hydrolysis with acidocomplexolysis at the same time or successively during the year within the zone above the water level (Righi and Leophelin, 1986) might have induced the reduction, dissolution and removal of hematite from the soil and/or its transformation to goethite.

5.2.3 Effects of other ecological factors on soil development.

The influence of climatic factor on the morphology and physical properties of the soils is not much. Parent material seems to be the dominant factor. Soil textural composition reflects the influence of parent material, local relief, and flood-water flow rate. For example, the sandy texture of soils of Gadza transect could be related to the sandstones geology of the area. Similarly, soils which occupied levees (pedons MD1, AR1 and AR4) were sandy whereas soils of backswamps and similar physiographic units (pedons MD2 to MD4, DM1, AR2, AR3 and AR5) were clayey. The clayey texture of pedons DM2, LD1 and LD2 could be related to their shaly parent materials. Effect of moisture stress could be seen by comparing the cracks formed in pedon LD1 (about 7cm wide) with those of pedon DM2 (about 3cm wide).

Even though soils with acid reactions were found in all ecosystems studied, horizons with soil reactions ranging from neutral through mildly alkaline to moderately alkaline were restricted to the drier sites (Dwam, Argungu and Lumda). Relatively low amounts of exchangeable bases and ECEC values of soils of Makurdi Gadza and Argungu transects could be linked with the similarity in geology (sandstones) of the areas. Soils of Dwam and Lumda transects were influenced by base-rich parent materials. Soils of Makurdi and Gadza transects had relatively higher exchangeable K^+ contents than exchangeable Na^+ whereas soils of drier sites (Dwam, Argungu and Lumda) contained higher exchangeable Na^+ than exchangeable K^+. Sodium in soils usually originates from primary silicates that contain Na or from organic matter (Al-Janabi and Lewis, 1982). The presence of salts and Na in pedon DM1 and all pedons of Argungu transect was most likely the result of nearness of groundwater containing some salts in solution. Repeated wetting and drying (as a result of evapotranspiration) and precipitation of salts has no doubt occurred. Pedons DM2, LD1 and LD2 had perched water tables because of their finer soil texture which prevented seasonal precipitation from leaching accumulated salts from the soil. Under such condition, Na might replace Ca on the exchange site (Al- Janabi and Lewis, 1982). Relatively high percent Na saturation in the lower horizons of all pedons of Argungu transect corroborates the significant effects of groundwater on the sodium concentration of the pedons.

All pedons of Makurdi and Gadza transects had low electrical conductivity (EC) values whereas salinity (as indicated by high EC values) was greater in soils of drier areas. Electrical conductivity (EC) measurement suggests that soils with perched water tables (e.g. pedons LD1 and LD2) and those on micro-depressions (e.g. pedons DM2, AR3 and AR5) contained high soluble salts.

5.3 Soil correlation and classification.

5.3.1 Correlation:

The soils were correlated based on reports of survey works done by Moss (1957), Carroll (1967), Klinkenberg (1967), Valette (1967), Hildebrand (1968), and Hildebrand and Valette (1969). The parent materials, topographic positions, colour and presence or absence of mottles, and soil texture were the main criteria used in correlating the soils.

All pedons of Makurdi transect (except pedon MD1) are heavy textured. Pedon MD1 is Santigi series. It is brownish in colour and has fairly clayey surface horizons. Pedon MD2 is brownish in colour and mottled below 97cm depth and is classified as Iju series. Pedons MD3 and MD4 belong to Edozhigi series. The two pedons are grayish, mottled and clayey. Pedon MD5 is reddish below the epipedon and is classified as Timfun series.

Pedons GZ5 and GZ6 occupy middle slope and upper slope positions respectively. Both of them are reddish in colour. Pedon GZ5 is classified as Kulfo series due to its greater depth of sandy layers (37- to 92cm depth) than pedon GZ6 (24-to 59cm, Appendix B) which is classified as Alagba series. Pedons GZ1 to GZ4 have sandy textures. Both pedons GZ1 and GZ2 are brownish gray but pedon GZ1 is mottled whereas pedon GZ2 is mottle-free. Pedon GZ1 is Ishaga series whereas pedon GZ2 is Mesan series. Pedon GZ4 has properties similar to GZ1 and therefore is also Ishaga series. Pedon GZ3 is classified as

Indaloke series based on its gray colour and presence of mottles.

Pedon DM1 is classified as Gbajigi series based on its silty clay texture, spongy consistence, brown colour and presence of mottles; whereas pedon DM3 which is underlain by limestone is Ashaka series. Both pedons AR1 and AR2 are brownish in colour and mottled. Pedon AR2 is classified as Sirti series because of its heavier texture while pedon AR1 is Tsantsaga series. Pedon AR3 has clayey texture, gray colour and mottles, and black concretions. It is classified as Shen series. Pedons AR4 and LD3 have similar properties. They are brownish in colour, mottled and sandy in texture. The two pedons are Barriki series. Pedon AR5 is Angwan series; it has brown colour, mottles and sandy clay to clay texture. Pedon AR6 is classified as Talbut series because of its yellowish brown colour, presence of mottles, and sandy loam to sandy clay loam texture.

Pedons DM2, LD1 and LD2 have vertic properties and are differentiated on the basis of their colours.

Thus, pedons LD1 and LD2 are classified as Giwano series because of the gray colour whereas pedon DM2 is Boskeri series due to the brown colour of its subsurface horizons.

5.3.2 Classification:

Pedons GZ1, GZ2, and GZ3 are seasonally flooded and are therefore considered to have aquic moisture regime. The pedologic soils properties related to an aquic moisture regime observed in these pedons include mottles of chroma 2 or less in the matrix, and high Al saturation (Fig. 12a). Leaching has been very intensive but the process of lessivage and thus argillic horizon formation is somewhat retarded. The presence of cambic horizon is supported by the weakly developed B horizens observed in pedons GZ2 and GZ3, and very fine sandy loam texture in pedon GZ1. Thus, these pedons could be classified as Inceptisols; and Aquepts, because of the aquic moisture regime. The soils are Tropaquepts because there is probably little variation in soil temperature between the rainy season and the dry season at a depth of 50cm. The pedons are

Typic Tropaquepts because they do not have histic epipedon and cracks but have chromas 2 in all horizons. The mean annual soil temperature at 50cm depth is taken as 27°C (due to the insignificant amplitude in soil temperature that has been associated with tropical soils). Therefore they belong to isohyperthermic temperature regime. Fine sand mineralogy of the pedons is dominated by quartz. Hence pedons GZ1, GZ2 and GZ3 are classified as Typic Tropaquept, coarse loamy, siliceous, isohyperthermic.

Pedons MD1, MD2, MD3, and GZ4 are classified as Entisols. They have soft epipedons and little or no B horizon development. Both pedons MD3 and GZ4 are considered to have aquic moisture regime while pedons MD1 and MD2 have ustic (dry in some parts for 90 or more cumulative days in most years), and udic moisture regimes respectively. Pedon GZ4 has loamy fine sand texture but less than 35 percent rock fragments in all subsoil horizons to a depth of 169cm. It is therefore a Psamment. It contained more than 90 percent quartz in the fine sand fraction. The pedon is qualified as Aquic Quartzipsamment. The irregular decrease of organic carbon with depth in pedons MD1, MD2 and MD3 made them to qualify as Ustifluvent, Udifluvent and Fluvaquent respectively. Pedon MD1 has neither mottles nor cracks. It is therefore a Typic Ustifluvent whereas pedon MD2 is Typic Udifluvent since it has neither aquic moisture regime nor mollic epipedon. Pedon MD3 has horizons with texture finer than loamy fine sand in the upper 75cm depth. It is therefore an Andaqueptic Fluvaquent. Pedon MD1 has predominantly quartz in the fine sand fraction whereas the clay mineralogy of pedons MD2 and MD3 (Table 5) is kaolinitic. Hence pedon MD1 is Typic Ustifluvent, fine loamy, siliceous isohyperthermic; pedon MD2 is Typic Udifluvent, fine clayey,kaolinitic, isohyper-thermic while pedon MD3 is Andaqueptic Fluvaquent, very fine clayey, kalonitic, isohyperthermic. Pedon GZ4 is Aquic Quartzipsamment (no particle size and mineralogy classes, Soil Survey Staff, 1987), isohyperthermic.

Pedons MD4, GZ5 and GZ6 are Ultisols because of evidence of intense leaching, presence of kandic and/or argillic horizons, tropical temperature and low base status (base saturation $< 35\%$ by sum of cations CEC pH. 8.2,). They have ustic moisture regime and are therefore classified as Ustults. They are Kandiustults because they have ECEC values less than 12cmol(+)kg^{-1} soil, a clay distribution whereby the percentage of clay does not decrease from its maximum amount by as much as 20 percent (Fig. 1) within a depth of 150 cm from the soil surface, and do not have a lithic or paralithic contact within 150cm of the soil surface. Pedons GZ5 and GZ6 are Typic Kandiustults because they are free of mottles and plinthite, have loamy sand to sandy loam epipedon and ECEC $>$ 1.5cmol(+)kg^{-1} soil in the major part of the argillic horizons; whereas pedon MD4 has mottles of high chroma below 22cm depth and therefore is Aquic Kandiustult. Hence pedons GZ5 and

GZ6 are Typic Kandiustult, fine clayey, kaolinitic, isohyperthermic; whereas pedon MD4 is Aquic Kandiustult, very fine clayey, kaolinitic, isohyperthermic. Pedons MD5 and DM3 have properties similar to those observed in pedon MD4 except that they have base saturation of $>$ 35% (sum of cations, CEC determined at pH 8.2,) which made them to be classified as Alfisols. Therefore, pedons MD5 and DM3 are classified as Typic Kandiustalf, fine clayey, kaolinitic, isohyperthermic.

Pedons DM1, AR1, AR2 and AR3 have properties similar to the pedons classified earlier as Entisols. They have aquic moisture regime as evident in the prominent mottling and dominant colour in the matrix of 10YR hue and chroma 2 or less. They are therefore Aquents. Pedons AR1 and AR2 have organic carbon distribution that decreased irregularly with depth (Table 1) and a texture finer than loamy fine sand in subsoil horizons between 25cm and 1.0m depth typical of Fluvaquents. The tropical temperature and absence of sulfidic materials within 50cm of the soil surface were used to classify pedons DM1 and AR3 as Tropaquents. The clayey texture of the epipedons of pedons AR1 and AR2 qualified them as Andaqueptic Fluvaquents. Subgroups of Tropaquents have not been defined (Soil Survey Staff, 1987). Therefore pedon AR1 is Andaqueptic Fluvaquent, fine loamy, siliceous, isohyperthermic; whereas pedon AR2 is Andaqueptic Fluvaquent, clayey over loamy, kaolinitic, isohyperthermic. Pedon DM1 is classified as Tropaquent, fine clayey, kaolinitic, ischyperthermic; whereas pedon AR3 is Tropaquent clayey over loamy, kaolinitic, isohyperthermic.

The vertic properties of pedons DM2, LD1 and LD2 were expressed by the presence of wide cracks which extended to about 42cm, 38cm and 44cm soil depths respectively, slickensides, grayish matrix colour, a basic (alkaline) soil reaction (Table 1), weak horizon development, and predominance of 2:1 expanding clay minerals (smectite). They are therefore classified as Vertisols. The soils are Usterts because the cracks remained open throughout the dry season (spanning more than 90 days). Pedons DM2 and LD2 are Chromusterts because they have chroma, moist of >1.5 in the upper 30cm whereas pedon LD1 is Pellustert having chroma of <1.5 in the upper 30cm depth. Both pedons DM2 and LD2 have colour value less than 3.5 in the epipedon but the cracks in pedon LD2 are likely to remain open for longer period of time because of the short duration of rainfall in most years in Lumda. Thus pedon DM2 is classified as Udic Chromustert, very fine clayey, montmorillonitic, isohyperthermic. Pedon LD1 has colour value, moist of <3.5 in the surface horizons and the cracks are likely to remain open for long period of time in most years. It is therefore classified as Typic Pellustert, very fine clayey, montmorillonitic, isohyperthermic; whereas pedon LD2 is Typic Chromustert, fine clayey, montmorillonitic, isohyperthermic.

Pedons AR4 and LD3 could be classified as Inceptisols because of evidence of intense leaching, presence of cambic horizon and loamy fine sand texture. The soils are mottled and have chromas too high for Aquepts, and because of absence of volcanic materials, plaggen and ochric epipedon, the tropical climate was used to place them into Tropepts; because of the ustic moisture regime they are Ustropepts. Pedon AR4 is Typic Ustropept, loamy fine sand, siliceous, isohyperthermic because it has mottles with chroma >2, organic matter that decreases regularly with depth, no cracks and no lithic contact within 50cm of the soil surface. Pedon LD3 has properties similar to those of pedon AR4 but because of its irregular decrease of organic matter with depth and high CEC values in the cambic horizons it is classified as Oxic Ustropept, loamy fine sand, siliceous, isohyperthermic.

The presence of kandic (typified in pedon AR5) and argillic horizons (in pedon AR6), base saturation $>35\%$ (sum of cations, pH 8.2), tropical climate and evidence of leaching qualified pedons AR5 and AR6 as Alfisols. Pedon AR5 has udic moisture regime whereas the moisture regime of pedon AR6 which is an upland soil is ustic. Hence they are Udalf and Ustalf respectively. The clay distribution in pedon AR5 is such that the percentage of clay does not decrease by as much as 20 percent of the maximum within a depth of 150cm from the soil surface. In addition, the pedon has many coarse mottles with chroma >5 in some subsoil horizons. Pedon AR5 is therefore a Paleudalf. Pedon AR6 is Haplustalf because it has no duripan, plinthite, natric horizon; but the argillic horizons have hue $>$5YR. Pedon AR5 is Albaquic Paleudalf because it has an increase of more than 15 percent clay at the upper boundary of the kandic horizon. Pedon AR6 has cation exchange capacity too low (ECEC $<$ 18cmol(+)kg^{-1} soil) for Typic Haplustalf, hence it is Kanhaplic Haplustalf. Pedon AR5 is therefore classified as Albaquic Paleudalf, fine clayey, mixed, isohyperthermic; whereas pedon AR6 is Kanhaplic Haplustalf, fine loamy, siliceous, isohyperthermic.

The FAO - Unesco equivalent for pedons GZ1, GZ2 and GZ3 is Dystric Gleysol because their profiles are dominated by hydromorphic soil-forming processes as shown in the low chroma. They have low percent base saturation and concomitant high Al saturation. Pedons MD4, GZ5 and GZ6 have low base saturation in part of the B horizons. However, while pedon MD4 has some hydromorphic properties (mottling), pedons GZ5 and GZ6 are free of mottles. Therefore, FAO - Unesco equivalent for pedon MD4 is Gleyic Acrisol whereas pedons GZ5 and GZ6 are Haplic Acrisols.

Pedons MD1, MD2, MD3 and DM1 occur in the flood-plains of River Benue whereas pedons AR1, AR2 and AR3 are soils which occur in the floodplain of River Sokoto. They are all flooded or saturated at the peak of flooding and have fluvic properties (Fluvisols) e.g. irregular decrease in organic carbon content with depth (typified in pedon MD3). The FAO-Unesco equivalent for pedons MD1, MD2, AR1 and AR2 is Dystric Fluvisol because of the low base saturation, whereas pedons MD3, AR3 and DM1 are Eutric Fluvisols because of their relatively high base saturation. The FAO-Unesco equivalent for pedons DM2, LD1 and LD2 is Eutric Vertisol because of their high base saturation and lack of calcic and/or gypsic horizons.

The upland pedons with low CEC and high base saturation (pedons MD5 and DM3) are Lixisols, whereas those with high CEC and base saturation (Pedons AR5 and AR6) are Luvisols. The FAO-Unesco equivalent for pedons MD5 and DM3 is Haplic Lixisol, whereas both pedons AR5 and AR6 are Haplic Luvisols. The coarse textured pedons GZ4 and LD3 are Arenosols. However, because pedon GZ4 shows some hydromorphic properties it is a Gleyic Arenosol whereas the FAO-Unesco equivalent for pedon LD3 is Cambic Arenosol because of the presence of a cambic B horizon. Pedon AR4 has a cambic horizon and because of evidence of alternating wet and dry moisture conditions it is a Gleyic Cambisol.

Soil Taxonomy classification system and FAO-Unesco legend are sometimes poorly correlated in particular for hydromorphic soils (Okusami *et al.*, 1987). This has been demonstrated in the classifications of pedons MD3 and AR1, and in pedons LD3 and AR4. Both pedons MD3 and AR1 are Andaqueptic Fluviaquents (Soil Survey Staff, 1987) but differ slightly when FAO-Unesco (1988) system is applied mainly because of differences in base saturation. Even though the two pedons have cambic horizons, pedon LD3 is an Arenosol because of its coarse texture.

5.4 Potential Productivity of the Soils for swamp rice (*Oryza sativa* L) and dry Season Sorghum (*Sorghum bicolor* (L) Moench).

Soil and water management are important in rice cultivation. Potential productivity evaluation is useful in predicting the suitability of any soil for agricultural use.

Soils of Makurdi transect have relatively high potential productivity index (P = 0.45) for swamp rice compared with soils of other transects. The mean potential productivity indices for Gadza, Dwam, Argungu and Lumda transects are 0.36, 0.30, 0.18 and 0.09 respectively (Table 6). Most of the soils (except pedons DM2, LD1 and LD2) are of low activity kaolinitic clay type (Table 5). The influence of climatic factor becomes prominent when comparing Makurdi and Gadza sites (guineo-congolian) on one hand, with Dwam, Argungu and Lumda sites (Sudanian/ Sahelian savannas) on the other hand. Potential productivity indices (P) values obtained by multiplicative approach is usually less than 1.0 unless all the factors considered are optimum.

In Makurdi sequence, pedon MD3 has the highest P value (0.57), followed by pedon MD4 (P = 0.51), pedon MD2 (P = 0.38), and pedon MD1 (P = 0.32). This is due to the soil drainage and salinity conditions in pedons MD3 and MD4 which are optimum for swamp rice. Pedon MD3, however, contains more weatherable minerals than pedon MD4. Also pedons GZ3 and GZ2 have higher P values (0.43 and 0.40 respectively) than pedons GZ1 (P = 0.30) and GZ4 (P = 0.29) due to

Table 6: Potential productivity indices of the soils

Pedon	Soil depth and drainage (D)	Soil texture (T)	Nature of clay (A)	Mineral reverve (M)	Salinity (S)	Rainfall condition (C)	Productivity index (P)	Mean P
Makurdi transect								
MD1	0.75	0.90	0.90	0.85	0.80	0.78	0.32	
MD2	0.75	0.90	0.90	0.95	0.84	0.78	0.38	
MD3	1.00	0.90	0.90	0.95	0.95	0.78	0.57	0.45
MD4	1.00	0.90	0.90	0.85	0.95	0.78	0.51	
Gadza transect								
GZ1	0.75	0.85	0.90	0.85	0.84	0.74	0.30	
GZ2	1.00	0.85	0.90	0.85	0.84	0.74	0.40	
GZ3	1.00	0.81	0.90	0.95	0.84	0.74	0.43	0.36
GZ4	0.75	0.81	0.90	0.85	0.84	0.74	0.29	
Dwam transect								
DM1	0.80	0.90	0.95	0.95	0.79	0.58	0.30	0.30
DM2	0.75	0.90	1.00	0.95	0.78	0.58	0.29	
Argungu transect								
AR1	0.80	0.90	0.90	0.85	0.80	0.42	0.18	
AR2	0.80	0.90	0.90	0.95	0.95	0.42	0.25	
AR3	1.00	0.90	0.90	0.95	0.50	0.42	0.16	0.18
AR4	0.75	0.85	0.90	0.85	0.95	0.42	0.19	
AR5	0.80	0.99	0.90	0.95	0.40	0.42	0.11	
Lumda transect								
LD1	0.75	0.90	1.00	0.95	0.50	0.42	0.13	
LD2	0.75	0.83	1.00	0.95	0.50	0.42	0.12	0.09
LD3	0.40	0.50	0.95	0.85	0.40	0.42	0.03	

better soil drainage and salinity conditions.

The major limiting factors for swamp rice production in Dwam sequence are rainfall and soil drainage. Pedons DM1 and DM2 have P values of 0.30 and 0.29 respectively (Table 6). Pedon DM2 contains better clay mineral type (smectite) than pedon DM1 (mixture of clays or hydrous micas) but has a poorer salinity condition. Rainfall factor is the main limitation for soils of Argungu and Lumda sequences. Pedons AR1 (P = 0.18) and AR4 (P = 0.19) are somewhat poorly-drained whereas pedon AR2 (P = 0.25) is poorly-drained. Salinity is another factor that significantly affected the potential productivity of pedons AR3 (P = 0.16) and AR5 (P = 0.11) (Table 6). Drainage, salinity and climatic factors are the main limitations of pedons LD1 (P = 0.13) and LD2 (P = 0.12) Of all the pedons rated for swamp rice production, pedon LD3 has the lowest P value (0.03) due to its highly sandy texture, high salinity, low rainfall and soil drainage (Table 6). From the results obtained, the potential productive (P) indices of the soils are rated as follows:

P value	Rating
0.41 - 1.00	high
0.20 - 0.39	medium
<0.20	low

The main pedological constraint on intensified swamp rice production in the inland valley lowland, river floodplains and terraces is the low activity clay type. This is due in part to the fact that their alluvial and colluvial parent materials were derived from old and well-leached upland soils. In addition, these upland soils were mainly derived from acidic rocks of the Basement complex or sedimentary rocks derived from Basement complex. The only soils formed from base-rich materials are those of pedons DM2, LD1 and LD2.

The other main technical constraints on wetland development are water availability and salinity. There are two major hydrological problems, first the length of the period of flooding which is related to the dry-season depletion curve and second the depth of wet-season flooding. The first problem is controlled to a great extent, by the groundwater characteristics which are in turn related to lithology. The length of time and depth of wet-season flooding are related to wetland topography, with the soils in the lowest topographic positions and depressions having deeper and longer flooding periods. The depth of flooding is an important determinant for the rice variety to be cultivated and, in the deeper flooded areas (e.g. around pedon AR3) deep-water varieties would be needed. In addition, if the length of flooding is short (as may be the case in Lumda), early-maturing varieties would be required. Salinity is a problem that is connected with nearness of salt-rich groundwater to the soil surface and occurrence of perched water table. The problem is prominent in the drier parts (Sudanian and Sahelian savannas) of the study area.

Most wetlands eventually dry out at the surface during the dry-season. The depth of water table is then important in determining if dry-season cultivation can occur. This depends on the moisture-holding capacity of the soils and the dry-season depletion curve due to evapotranspiration. The main factor considered for sorghum (Sorghum bicolor (L) Moench) is soil texutre since this is directly related to the moisture-holding capacity of the soil. The amount of water held by the soil determines the amount that would be available for plant use in the dry-season. Salinity factor is not considered for sorghum because all pedons studied have electrical conductivity values within the tolerable level (sorghum tolerates up to $5dSm^{-1}$). Therefore, only fine textured wetland soils (e.g. pedons MD2, MD3, MD4, DM1, AR2, AR3 and AR5) which would not dry out early in the dry-season may be suitable for dry-season cultivation of sorghum. Experience in New Marte (near Lumda) indicates that Vertisols occupying depressions could be used for dry-season cultivation of 'Firki' sorghum based on sub-soil moisture reserves. In other places (Gadza, Makurdi, Dwam and Argungu), some wetland soils are being used for dry-season cultivation of cowpea, vegetables and early-maturing varieties of sweet cassava (e.g. TMS4(2) - 1425). Soils of Gadza transect and those that occupied levees are sandy and therefore could not retain enough moisture for dry-season cultivation of sorghum. However, these soils could possibly be used for vegetables.

CHAPTER SIX

6.0 SUMMARY AND CONCLUSIONS

The soils of inland valley lowland (e.g. pedon GZ3) and floodplain depressions (pedons MD3, DM2, AR3) were generally grayish brown and mottled below the epipedon in addition to presence of sesquioxidic nodules/concretions (pedons MD4 and DM1), whereas the well-drained upland soils had red hues (2.5YR - 5YR) and were free of mottles. The presence of significant amounts of hematite in the clay fractions of the well-drained pedons MD5, GZ5 and GZ6 corroborate their reddish colour. The decreasing redness of soils downslope could be ascribed to increasing hydration of iron or better still due to changes in iron form. Gleization was evident in pedon GZ2 by the presence of a permanently high groundwater table and a mottle-free grayish colour with low chroma. Pedons DM2, LD1 and LD2 were distinctly different from the other pedons by the occurrence of vertic properties (dark grayish colour, wide cracks and slickensides) in them. However, the vertic properties were more developed in pedon LD1.

The topsoil and subsoil textures of the pedons were quite variable and reflected the influence of parent material and floodwater flow rate. The low-land soils of Gadza transect (pedons GZ1 to GZ4) including those of levees in Makurdi and Argungu transects (pedons MD1, AR1 and AR4) and sand ridge (pedon LD3) were generally sandy, whereas soils of backswamps and depressions had heavier textures. Accumulation of clay materials at the epipedons of pedons AR2 and AR3 which occupied the backswamp, is a reflection of floodwater flow/deposition rate. Pedons MD5, GZ5, GZ6, DM3, AR5 and AR6 have B horizons that contained higher clay contents than both A and C horizons. The influence of climatic variation among the sites on the morphology and physical properties of soils is not much. Parent material seems to be the dominant factor. Soil textural composition reflects the influence of parent material, local relief and floodwater flow rate.

Soils of Makurdi and Gadza transects were generally acidic, whereas those of Dwam, Argungu and Lumda transects had soil reactions ranging from acid through neutral to alkaline. Low base status soils dominate in Gadza and Makurdi transects whereas some soils of transects in Sudanian (Dwam and Argungu) and Sudanian/Sahelian savanna (Lumda) were of high base status. Pedons with horizons wich in smectitic clay (Pedons DM2, LD1 and LD2) had relatively high ECEC values. Such horizons include Bw2 (74-109cm) of pedon DM2, Bw2 (57-96cm) of pedon LD1, and 2Bw2 (85-117cm) of pedon LD2 with ECEC values of 30.68, 31.12 and 20.31cmol(+)kg^{-1} of soil respectively. Howeyer, pedon DM3 and all pedons of Argungu transect (except pedon AR3) had relatively low ECEC values. All pedons of Makurdi and Gadza transects had low electrical conductivity (EC) values whereas salinity (as indicated by high EC values) was greater in soils of drier areas (Dwam, Argungu and Lumda). Electrical conductivity measurement suggests that soils with perched water tables (e.g. pedons LD1 and LD2) and those on micro-depressions (e.g. pedons DM2, AR3 and AR5) contained high soluble salts. The higher $Fe_2O_{3(d)}$/clay ratios with soil depth observed in pedons GZ2, GZ3, DM2 and AR3 indicate a co-migration or parallel eluviation of iron and clay, whereas higher $Fe_2O_{3(d)}$/clay ratios in B horizons than in A horizons (e.g. in pedons MD1, MD2, GZ5, AR1 and LD2) indicate independent $Fe_2O_{3(d)}$ migration.

Quartz dominated the sand mineralogy, with varying amounts of feldspar, muscovite, zircon and biotite. The silt mineralogy consisted of quartz, mica, kaolinite and vermiculite. The clay mineralogy of the soils is greatly influenced by the parent material and topography. Most of the soils were kaolonitic, but the soils derived from shale-dominated materials (pedons DM2, LD1 and LD2) were smectitic; some others on depressions (pedons MD3 and AR5) had horizons containing 2:1 expanding clay minerals (smectite).

There were evidences that eluvial/illuvial transportation processes and weathering 'in situ' have contributed towards horizon development and differentiation of pedons MD5, GZ5, GZ6, DM3, AR5 and AR6 as evidenced in the Bt horizon. The only noticeable active pedogenic process in pedons DM2, LD1 and LD2 was soil displacement, as evident by the presence of slickensides. Pedoturbation as a result of such displacement has been sufficient to prevent strong horizon development. The presence of relatively high Al saturation especially in pedons MD2, GZ2, GZ3, GZ4 and AR4, seems to support the ferrolysis concept of Brinkman (1970). Differential accumulation of Al especially in hydromorphic soils with perched water tables (e.g. pedon MD4) may indicate the actively weathering zone of the solum. The warm soil temperature conditions in savanna region of Nigeria are believed to cause the marked dissociation of soil water leading to a build-up of hydrogen ions, which favours hydrolytic or H-weathering of silicates to kaolinite. Some mineral transformations (e.g. of hematite to goethite) have been brought about by occurrence of hydrolysis with acidocomplexolysis within the zone above the water table.

The wetland soils are relatively young in terms of pedogenesis and are therefore predominantly Inceptisols and Entisols; whereas the adjoining upland soils are mainly Alfisols and Ultisols. However, Pedons DM2, LD1 and LD2, are Vertisols. All pedons with clayey textures are kaolinitic (except pedon AR5 which has mixed mineralogy) but the Vertisols are montmorillonitic Pedons with sandy and loamy textures are siliceous. All pedons have isohyperthermic temperature regime. Thus pedons GZ1, GZ2 and GZ3 are classified as Typic Tropaquept, coarse loamy; pedon AR4 is Typic Ustropept, loamy fine sand while pedon LD3 is classified as Oxic Ustropept, loamy fine sand. Pedon MD1 is Typic Ustifluvent, fine loamy; pedon MD2 is Typic Udifluvent, fine clayey, while pedon GZ4 is classified as Aquic Quartzipsamment. Both pedons MD3 and AR1 are classified as Andaqueptic Fluvaquent but pedon MD3 had very fine clayey texture while the other pedon is fine loamy. Similarly, pedon AR2 is classified as Andaqueptic Fluvaquent, clayey over loamy. Both pedons DM1 and AR3 are

Tropaquents but while pedon DM1 has fine clayey texture, the other pedon is clayey over loamy. Both pedons MD5 and DM3 are classified as Typic Kandiustalf, fine clayey. Pedon AR5 is Albaquic Paleudalf, fine clayey whereas pedon AR6 is Kanhaplic Haplustalf, fine loamy. Pedon MD4 is classified as Aquic Kandiustult, very fine clayey whereas both pedons GZ5 and GZ6 are Typic Kandiustults, fine clayey.

Pedon DM2 is classified as Udic Chromustert, very fine clayey; pedon LD1 is Typic Pellustert, very fine clayey while pedon LD2 is Typic Chromustert, fine clayey.

The FAO-Unesco equivalent for pedons GZ1, GZ2 and GZ3 is Dystric Gleysol; pedon MD4 is Gleyic Acrisols whereas pedons GZ5 and GZ6 are Haplic Acrisols. Pedons MD1, MD2, AR1 and AR2 are Dystric Fluvisols, whereas pedons MD3, AR3 and DM1 are Eutric Fluvisols. The FAO-Unesco equivalent for pedons DM2, LD1 and LD2 is Eutric Vertisol. Pedons MD5 and DM3 are classified as Haplic Lixisols whereas pedons AR5 and AR6 are Haplic Luvisols. Pedon GZ4 is Gleyic Arenosol whereas pedon LD3 is Cambic

Arenosol. The FAO-Unesco equivalent for pedon AR4 is Gleyic Cambisol.

The mean potential productivity indices (P) for lowland rice in Makurdi, Gadza, Dwam, Argungu and Lumda transects are 0.45, 0.36, 0.30, 0.18 and 0.09, respectively. Low soil fertility, poor water availability and high salinity are the main constraints. Only pedons MD2, MD3, MD4, DM1, AR2, AR3 and AR5, because of their fine textures, may be suitable for dry-season cultivation of sorghum.

REFERENCES

Adeleye, D.R. and Dessauvagie, T.F.T. 1970. Stratigraphy of the Niger embayment near Bida, Nigeria. In Dessauvagie, T.F.T. and Whiteman, A.J. (eds) African Geology, Ibadan, University of Ibadan. 181 - 186.

Alexander, E.B. 1974. Extractable Fe in relation to soil age on terraces along Truckee River, Nevada. Soil Science Society of America Proceedings, New York, 38: 121 - 124.

Al-Janabi, K.Z. and Lewis, D.T. 1982. Salt affected soils in the Platte River valley of central Nebraska: properties and classification. Soil Science Society of America Journal, New York, 46: 1037 - 1042.

Allison, L.E. 1965. Organic carbon. In Black, C.A. (ed). Methods of soil analysis, part 2. Agronomy 9: 1367 - 1378. American Society of Agronomy, Madison, Wisconsin, U.S.A.

Andriesse, W. 1986. Area and distribution. In Juo, A.S.R. and Lowe, J.A. (eds), The wetland and rice in subsaharan Africa. Proceedings of an international conference on wetland utilization for rice production in subsaharan Africa, IITA, Ibadan, Nigeria. 15-30.

Arduino, E., Barberis, E, Carraro, F., and Forno, M.G. 1984. Estimating relative ages from iron-oxide/total iron ratios of soils in the western Po valley, Italy. Geoderma, Amsterdam, 33: 39 - 52.

Arduino, E., Barberis, E, Ajmore Marsan, F, Zanini, E, and Franchini, M. 1986. Iron Oxides and clay minerals within profiles as indicators of soil age in northern Italy. Geoderma, Amsterdam, 37: 45 - 55.

Asamao, G.K. 1973. Particle size and free iron oxide distribution in some latosols and ground-water laterites of Ghana. Geoderma, Amsterdam, 10: 285 - 297.

Ashaye, T.I. 1969. Sesquioxide status and particle size distribution in twelve Nigerian soils derived from sandstone. African soils, Lagos, XIV: 85 - 86.

Ayotade, K.A. and Fagade, S.O. 1986. Nigeria's programm for wetland rice production and rice production and rice research. In Juo, A.S.R. and Lowe, J.A. (eds.) The wetland and rice in subsah aran African. Proceedings of an international conference on wetland utilization for rice production in subsaharan Africa. IITA, Ibadan, Nigeria. 251 - 260.

Ayotade, K.A. and Okereke, M. 1984. Small-scale swamp development in Nigeria. Paper presented at the FAO workshop on small-scale swamp development, Freetown, Sierra Leone. 21p.

Balster, C.A. and Parsons, R.B. 1968. Geomorphology and Soils. Willamette valley, Oregon, Oregon State Experimental Station, Special Report 265: 8 - 22.

Barber, W. 1965. Pressure water in the Chad formation of Bornu and Dikwa emirates, north-eastern Nigeria. Federal Republic of Nigeria, Ministry of Mines and Power, Geological survey of Nigeria Bullettin No 35: 138p.

Bigham, J.M., Golden, D.C., Buol, S.W., Weed, S.B., and Bowen, L.H. 1978. Iron oxide mineralogy of well-drained Ultisols and Oxisols: II. Influence on colour, surface area, and phosphate retention. <u>Soil Science Society of America Journal</u>, New York. 42: 825 - 830.

Bilzi, A.F. and Ciolkosz, E.J. 1977. Time as a factor in the genesis of four soils developed in recent alluvium in Pennsylvania. <u>Soil Science Society of America Journal</u>, New York, 41: 122.

Birkeland, P.W. 1974. Pedology, weathering and geomorphological research. New York, Oxford University Press.

Birkeland, P.W., Burke, R.M., and Walker, A.L. 1980. Soils and subsurface rock-weathering features of Sherwin and pre-Sherwin glacial deposits, eastern Sierra Nevada, California, Geological Society of America Bulletin, 91: 238 - 244.

Blake, G.R. 1965. Bulk density. In Black, C.A. (ed) Methods of soil analysis, part 1. Agronomy 9: 375 - 377. American Society of Agronomy Inc., Madison, Wisconsin, U.S.A.

Blokhuis, W.A. 1982. Relationships between morphological properties and drainage in Vertisols. Paper presented at the 5th International soil classification workshop, Khartoum and Wad Medani, Sudan. 16p.

Blume, H.P. and Schwertmann, U. 1969. Genetic evaluation of profile distribution of alluminium, iron, and manganese oxides. Soil Science Society of America Proceedings, New York, 33: 438 - 444.

Bouma, J. 1983. Hydrology and soil genesis of soils with aquic moisture regimes. In Wilding, L.P, Smeck, N.E. and Hall, G.F. (eds). Pedogenesis and soil taxonomy I. Concepts and interactions. Developments in Soil Science IIA. Amsterdam Elsevier Scientific Publishing Co, 253 - 281.

Bouma, J., Dekker, L.W., and Haans, J.C.F.M. (1980). Measurement of depth to the water table in a heavy clay soil. Soil Science, Baltimore, 130(5): 264 - 270.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. Soil Science Society of America Proceeding, New York 22: 464 - 465.

Bray, R.H. and Kurtz, L.T. 1945. Determination of total, organic and available forms of P in soil. Soil Science, Baltimore, 59: 39-45.

Bremner, J.M. 1965. Total Nitrogen. In Black, C.A. (ed). Methods of soil analysis, part 2.

207

Agronomy 9: 1149 - 1178. American Society of Agronomy Inc., Madison, Wisconsin, U.S.A.

Brewer, R. 1960. Fabric and mineral analysis of soils (2nd edition). New York, John Wiley and Sons Inc. 529p.

Brewer, R. and Walker, D.H. 1969. Weathering and soil development on a sequence of river terraces. Australian Journal of Soil Research. East Mebaune, 20: 293 - 305.

Brinkman, R. 1970. Ferrolysis, a hydromorphic soil forming process. Geoderma, Amsterdam, 3: 199 - 206.

Brinkman, R. 1978. Ferrolysis: Chemical and mineralogical aspects of soil formation in seasonally wet acid soils and some practical implications. In International Rice Research Insitute, Soils and Rice. IRRI, Los Banos, Philippines, 295 - 306.

Brown, F.B. 1969. Upland rice in Latin America. International Rice Commission Newsletter, volume 18: 1 - 5.

Buol, S.W. 1965. Present soil-forming factors and processes in arid and semi-arid regions. Soil Science, Baltimore, 99: 45 - 49.

Buol, S.W., Hole, F.D., and McCraken, R.J. 1980. Soil genesis and classification (2nd edition), Ames, Iowa State University Press. 404p.

Campbell, I.B. 1971. A weathering sequence of basaltic soils near Dunedin, New Zealand. New Zealand Journal of Soil Science. 14: 907 - 924.

Canada Soil Survey Committee, 1978. The Canadian System of soil classification. Canadian Department of Agriculture Publ. 1646, Supply and Services Canada, Ottawa. 164p.

Carroll, D.M. 1967. The soils of the Maiduguri Bama area. Soil Survey Bulletin No 40. Samaru Institute for Agricultural Research, 70p.

Carter, J.D. Barber, W; Tait, E.A.; and Jones, G.F. 1963. The Geology of parts of Adamawa, Bauchi and Borno provinces in North-Eastern Nigeria. Federal Republic of Nigeria, Ministry of Mines and Power. Geological survey of Nigeria Bulletin No. 30.

Chang, S.C. 1978. Evaluation of the fertility of rice soils. In International Rice Research Institute, Soils and Rice, Los Banos, Philippines, 521 - 541.

Clarke, G.R. 1951. Evaluation of soils. Journal of Soil Science, London. vol. 2, No. 1, 50-60.

Cole, N.H.A. 1973. Soil conditions, zonation and species diversity in a seasonally flooded tropical grass herb swamp in Sierra-Leone. Journal of Ecology, London, 61: 831-847.

Coventry, R.J., Taylor, R.M., and Fitzpatrick, R.W. 1983. Pedologic significance of the gravels in some red and grey earths of central north

Queensland. Australian Journal of Soil Research, East Melbourne, 21: 219-240.

Coventry, R.J. and Williams, J. 1984. Quantitative relations between morphology and current soil hydrology in some Alfisols in semi-arid tropical Australia. Geoderma, Amsterdam, 33(3): 191-218.

Cunningham, R.L., Giolkosz, E.J., Matelski, R.P., Peterson G.W. and Ranney, R.W. 1971. Characteristics, interpretations and uses of Pennsylvania soils: Armstrong Country, Pennsylvania Agricultural Experimental Station, Progress Report 316.

Daniels, R.B, Gamble, E.E., and Nelson, L.A. 1971. Relations between soil morphology and water table levels on a dissected north Carolina coast plain surface. Soil Science Society of America. Proceedins, New York, 35: 781-784.

Dasog, C.S., Acton, D.F., and Mermut, A.R. 1987. Genesis and classification of clay soils with vertic properties in Saskatchewan. Soil Science

Society of America Journal, New York, 51: 1243-1250.

De Datta, S.K. 1975. Upland rice around the world. In IRRI, Major Research in upland rice. International Rice Research Institute, Los Bonos, Laguna. 6-7.

De-Datta, S.K., Abilay, W.P. and Kalwar, G.N. 1973. Water Stress effects in flooded tropical rice. In IRRI, Water management in Philippine irrigation systems: research and operations. International Rice Research Institute, Los Banos, Philippines, 18-31.

D'Hoore, J.L. 1968. The classification of tropical soils. In Moss, R.P. (ed.) The Soil Resources of Tropical Africa, Cambridge University Press, 7-28.

Dixon, J.B. 1982. Kaolinite and serpentine group minerals. In Dixon, J.B. and Weed (eds.).

Minerals in soil environment. Soil Science Society of America Inc., Wisconsin, U.S.A., 357-403.

Durand, J.H. 1965. Etude pedologigue de la plaire de Boghe (Republique Islamique de Mauritanie). Tropical Agronomy, Paris, 20: 1284-1310.

Eswaran, H. and Bin. C.W. 1978. A study of a deep weathering profile on granite in Pennisular Malaysia: I. Physico-chemical and micromorphological properties. Soil Science Society of America Journal, New York, 1 (42): 144-149.

Fagbami, A. and Vega-Catalan, F. 1985. An evaluation of the physiographic soil map of the Benue valley at Makurdi. ITC Journal, The Hague (4): 268-274.

Falconer, J.D. 1911. The geology and geography of northern Nigeria, London, 150-154.

F.A.O. 1965. Agricultural development in Nigeria "1964-1980". FAO, Rome. 581p.

_____________ 1977. Guidelines for soil profile description (2nd edition). Soil Resources development and conservation serice, Land and Water development division, F.A.O. Rome 66p.

_____________ 1978. Report on the Agro-Ecological zones project vol. 1. Methodology and results for Africa. World Soil Resources Report 48. 158p.

F.A.O.-Unesco, 1988. FAO-Unesco soil map of the world, 1: 5000000. Revised Legend. World Soil Resources Report 60; Rome, 119p.

Fenton, T.E., Dietz, W.P., and Reicken F.F. 1974. Chemical properties of upland summit and associated cumulic soils in loess areas of Tama Country, Iowa, Agronomy Abstract, Wisconsin U.S.A. 158p.

Fey, M.V. and LeRoux, J. 1977. Properties and quantitative estimation of poorly crystalline components in sesquioxidic soil clays. Clays and clay minerals. 25: 285-294.

Gallez, A, Juo, A.S.R., and Herbillon, A.J. 1976. Surface and charge characteristics of selected soils in the tropics. Soil Science Society of America Proceedings, New York, 40: 601-608.

Gerrard, A.J. 1981. Soils and Landforms. An integration of geomorphology and pedology. London, George Allen and Unwin. 219p.

Gile, L.H. and Grossman, R.S. 1968. Morphology of the argillic horizon in desert soils of southern New Mexico. Soil Science, Baltimore, 106: 6-15.

Gotoh, S. 1976. Distribution of total and extractable forms of iron, manganese, and aluminium in development of rice soils of Saga polder lands. Soil Science and Plant Nutrition, Tokyo, 22: 335-344.

Gotoh, S. and Patrick, W.H. Jr. 1974. Transformation of iron in a waterlogged soil as influenced by redox potential and pH. Soil Science Society of America Proceedings, New York, 38: 66-71.

Grim, R.E. 1968. Clay mineralogy. New York, McGraw-Hill. 41-73.

Grove, A.T. 1970. Africa south of the Sahara. (2nd edition). London, Oxford University Press. 280p.

Guthrie, R.L. and Hajek, B.F. 1979. Morphology and water regime of a Dothan soil. Soil Science Society of America Journal, New York, 43: 142-144.

Hildebrand, F.H. 1968. A reconnaisance survey of the Serti area Sardauna Province, northern Nigeria. Soil Survey Bulletin No 37. Samaru, Institute for Agricultural Research, Ahmadu Bello University, 38p.

Hildebrand, F.H. and Valette, J. 1969. A reconnaissance survey of the Wase-Ibi area, Benue-Plateau State Nigeria. Soil Survey Bulletin No 39. Samaru, Institute for Agricultural Research, Ahmadu Bello University, 25p.

Hugie, U.K. and Passey, H.B. 1963. Cicadas and their effect on soil genesis in certain soils of southern Idaho, northern Utah, and northeastern Nevada. Soil Science Society of America Proceedings, New York, 27: 78-82.

I.I.T.A., 1975. Selected methods for soil and plant analysis. International Institute of Tropical Agricultural, manual series no 1, 70p.

I.I.T.A., 1982. Automated and semi-automated methods for soil and plant analysis. International Institute of Tropical Agriculture, manual series no. 7: 6-8.

I.R.A.T., 1970. The rice research programme of IRAT-results and outlook. Proceedings of Ford Foundation/IITA/IRAT seminar on rice research, Ibadan, Nigeria. 1-12.

I.R.R.I, 1963. Water regime in flooded soils. In International Rice Research Institute, Los Banos, Philippines (IRRI), 1964 Annual Report. 83-88.

__________ 1988. International rice research newsletter. IRRI. 13(5): 38p.

Jackson, M.L. 1956. Soil chemical analysis - Advanced coarse. Department of Soils, University of Wisconsin, Madison 6, Wisconsin, U.S.A., 894p.

________ 1965. Clay transformations in soil genesis during the Quaternery. Soil Science, Baltimore, 99: 15-22.

Jenny, H. 1941. Factors of soil formation. A system of quantitative pedology. New York, McGraw-Hill 20-42.

Jones, M.J. and Wild, A. 1975. Soils of the West African savanna (the maintenance and improvement of their fertility). Technical Communication No 55 of the Commonwealth Bureau of Soils, Harpendon. 16-30.

Juo, A.S.R., Moormann, F.R. and Maduakor, H.O. 1974. Forms and pedogenetic distribution of extractable Fe and Al in selected soils of Nigeria.

Geoderma, Amsterdam, 11: 167-179.

Kadeba, O. and Benjaminsen, J.N. 1976. Contribution of organic matter and clay to the CEC of soils in the savanna zone of Nigeria. Communications in Soil Science and Plant Analysis, New York, 7(2): 129-144.

Kampf, N. and Schwertmann, U. 1983. Goethite and hematite in southern Brazil and their application in classification of kaolinitic soils. Geoderma, Amsterdam, 29: 27-39.

Kanehiro, Y. and Sherman, G.D. 1965. Fusion with Na_2CO_3 for total elemental analysis. In Black, C.A. (ed.) Methods of soil analysis, part 2. Agronomy 9: 952 - 958. American Society of Agronomy, Madison, Wisconsin, U.S.A.

Kanno, I. 1978. Genesis of rice soils with special reference to profile development. In International Rice Research Institute, Soils and Rice, IRRI, Los Banos, Philippines. 237-253.

Kantor, W. and Schwertmann, U. 1974. Mineralogy and genesis of clays in red-black soil toposequence of basic igneous rocks in Kenya. Journal of Soil Science, London, 25: 67-78.

Karathanasis, A.D. and Hajek, B.F. 1982. Revised methods for rapid quantitative determination of minerals on soil clays. Soil Science Society of America Journal, New York, 46: 419-425.

Kawaguchi, K., Hattori, T. and Waki, T. 1957. Some chemical and mineralogical studies of polder land in Kojima Basin, Okayama Prefecture, Soil Plant Food, Tokyo 3: 7-14.

Kawaguchi, K. and Kyuma, K. 1977. Paddy soils in tropical Asia, their material nature and fertility. Honolulu, The University Bress of Hawaii. 258p.

Keng, J.C.W. and Uehara, G. 1974. Chemistry, mineralogy and taxonomy of Oxisols and Ultisols. Florida, Soil and Crop Society of Florida, 33: 119-126.

Klinkenberg, K. 1967. The soils of the Lau-Kaltungo area. Soil Survey Bulletin No 36. Samaru, Institute for Agricultural Research, Ahmadu Bello University, 70p.

Kogbe, C.A. 1973. Geology of the upper Cretaceous and Tertiary sediments of the Nigerian sector of the Iullemeden Basin (West Africa). Geology Rundschau. 62(1): 197-211.

Krouberg, B.I. and Nesbitt, H.W. 1981. Quantification weathering, soil geochemistry and soil fertility. Journal of Soil Science, London, 32: 453-459.

Kyuma, K. 1978. Mineral composition of rice soils. In International Rice Research Institute, Soils and Rice, IRRI, Los Banos, Philippines, 219-235.

Mckeague, J.A. and Day, H.H. 1966. Dithionite and oxalate extractable Fe and Al as aids in differentiating various classes of soils. Canadian Journal of Soil Science, Ottawa; 46: 33-38.

Mckeague, J.A., Brydon, J.E., and Miles, N.M. 1971. Differentiation of forms of extractable iron and aluminium in soils. Soil Science Society of America Proceedings, New York, 35: 33-38.

Mclean, E.O. 1965. Aluminium. In Black, C.A. (ed). Methods of soil analysis, part 2. Agronomy 9: 978-997.

Mehra, O.P. and Jackson, M.L. 1960. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. Clays and clay minerals monograph, Earth Science series, New York, 5: 317-327.

Mekaru, T. and Uehara, G. 1972. Anion adsorption in ferruginous tropical soils. Soil Science Society of America Proceedings, New York 36: 296-300.

Milne, G. 1935. Some suggested units of classification and mapping particularly for east African soils. Soil Research, London 4, No. 3: 1-6.

Milne, G. 1936. A provisonal soil map of east Africa. East African Agricultural Research Station, Amani, memograph no 34:, 32p.

Mitra, R.R. and Mandal, L.N. 1983. Distribution of forms of Fe and Mn in rice soils of West Bengal in relation to soil characteristics. Journal of Indian Society of Soil Science, New Delhi. 31: 38-42.

Mohr, E.C.J., Van Baren, F.A., and Van Schuylenborgh, J. 1972. Tropical Soils. The Hague, Monton-Ichtair Baru-Van Hoeve. 18-102.

Moore, P.D. and Bellamy, D.J. 1974. Peatland, New York, Springer-Verlag, 1-60.

Moormann, F.R. and van Breemen, N. 1978. Rice: Soil, Water, Land. International Rice Research Institute, Los Banos, Philippines. 185p.

Moormann, F.R. and van de Watering, H.T.J. 1985. Problems in characterising and classifying wetland soils. In International Rice Research Institute, Wetland soils: characterization, classification, and utilization. Proceedings of a workshop, 26 March - 1 April, Los Banos, Phillippines. 53-68.

Moss, R.F. 1957. Report on the classification of the soils found over sedimentary rocks in western Nigeria. Soil Survey Report No 67. IAR&T, University of Ife, Ibadan. 56p.

Murtha, G.G. and Williams, J. 1986. Measurmment, prediction and interpretation of soil temperature for use in soil taxonomy: Tropical Australian experience. Geoderma, Amsterdam, 37: 189-206.

Nettleton, W.D., Flach, K.W., and Brasher, B.R. 1969. Argillic horizons without clay skins. Soil Science Society of America Proceedings, New York, 33: 121-125.

Ogunwale, J.A. and Ashaye, T.I. 1975. Sandstone-derived soils of a catena at Iperu, Nigeria. Journal of Soil Science, London, 26(1): 22-31.

Ojanuga, A.G. 1977. Forms of sesquioxides in Iwo soils. Nigeria Agricultural Journal, Ibadan. 14: 1-12.

Ojanuga, A.G. 1979. Clay mineralogy of soils in the Nigerian tropical savanna regions. Soil Science Society of America Journal, New York, 43: 1237-1242.

Okuda, A. and Takahashi, E. 1964. The role of silicon. In International Rice Research Institute, The mineral nutrition of the rice plant. Maryland, John Hopkins Press, Baltimore. 63-101.

Okusami, T.A., Rust, R.H. and Juo, A.S.R. 1985. Characteristics and classification of some soils formed on post-cretaceous sediments in southern Nigeria. Soil Science, Baltimore, 140(2): 110-119.

__________ 1987. Properties and classification of five soils on alluvial lanforms in central Nigeria. Canadian Journal of Soil Science, Ottawa, 67: 249-261.

Park, G.A. 1967. Aqueous surface chemistry of oxides and complex oxide minerals. Isoelectric point and zero point of charge. In Gould R.F. (ed), Advances in Chemistry series, New York 67: 121-160.

Parsons, R.B. and Herriman, R.C. 1975. Geomorphic surfaces and soil development, Upper Rogue River valley, Oregon. Agronomy Abstract, Wisconsin, USA. 154p.

Patrick, W.H. Jr. and Delaune, R.D. 1972. Characterization of the oxidized and reduced zones in flooded soil. Soil Science Society of America Proceedings, New York, 36: 573-576.

Patrick, W.H. Jr. and Reedy, C.N. 1978. Chemical changes in rice soils. In International Rice Research Institute, Soils and Rice, IRRI, Los Banos, Philippines, 361-379.

Patrick, W.H. Jr. and Turner, F.T. 1968. Effect of redox potential on manganese transformation in waterlogged soil. Nature, Massachusetts, 20: 476-478.

Pedro, C. Jamague M., and Bagon, J.C. 1969. Mineral interactions and transformations in relation to pedogenesis during the Quarternary. Soil Science, Baltimore, 107(6): 462-469.

Phillips, J. 1959. Agriculture and ecology in Africa- A study of actual and potential development south of the Sahara. London, Faber and Faber, 424p.

Pickering, E.W. and Veneman, P1L.M. 1984. Moisture regimes and morphological characteristics in a hydrosequence in central Massachusetts, Soil Science Society of America Journal, New York, 48: 113 - 118.

Pugh, J.C. and King, L. 1952. Outline of the geomorphology of Nigeria. South African Geographic

Journal, Johannesburg, 34: 30-37.

Purnell, M.F. 1979. Vertisols and their utilization in West Africa. International Institute of Tropical Agriculture, Annual Research Conference, October 15-19: 22p.

Ragland, J.R. and Coleman, T.N. 1959 . The effect of soil solution aluminium and calcium in root growth. Soil Science Society of America Proceedings, New York, 23: 355-357.

Rebertus, R.A. and Buol, S.W. 1985. Iron distribution in a developmental sequence of soils from mica gneiss and schist. Soil Science Society of America Journal, New York, 49: 713 - 720.

Richardson, C.J. 1979. Primary productivity values in fresh water wetlands. In Greeson, P.E. (ed) Wetland functions and values: The state of our understanding. Proceedings of National symposium on wetlands. Lake Buena Vista, Florica. 7-10 November. American Water Resources Association. Minneapolis, 131-145.

Richardson, J.L. and Hole, F.D. 1979. Mottling and iron distribution in a Glossoboralf-Haplaguoll hydrosequence on a glacial moraine in northwestern Wisconsin. Soil Science Society of America Journal, New York, 43: 552-558.

Righi, D and Lorphelin, L. 1986. Weathering of silt and clay in soils of a toposequence in the Himalayas, Nepal. Geoderma, Amsterdam, 39: 141-155.

Russ, W. 1930. The Minna-Birnin Gwari Belt. Geological Survey of Nigeria Report. 20-21.

Sanchez, P.A. 1976. Properties and management of soils in the tropics. New York, John Wiley and Sons, Inc. 325p.

Sanford, W.W. and Isichei, A.O. 1986. Savanna. In Lawanson, G.W. (ed) Plant Ecology in West Africa, Systems and Processes. John Wiley and Sons Ltd. New York. 95-149.

Santos, M.C.D., St. Arnaud, R.J., and Anderson, D.W. 1986. Quantitative evaluation of pedogenetic changes Boralfs (Gray Luvisols) of east central Saskatchewan, Soil Science Scoeity of America Journal, New York, 50: 1013-1019.

Sarmiento, G. and Monasterio, M. 1975. A critical consideration of the environmental conditions associated with the occurrence of savanna ecosystems in tropical America. In Jacobs, J. Lange, M.O.L., Olson, I.S., Nieser, D.W., and Inusbruck, T. (eds), Ecological studies 11: Tropical Ecological system, U.S.A. 223 - 250.

Schlichting, S. Von. 1973. Pseudogleye und gleye-Genese und nut-zung hydromorpher boden. In Schlichting E and Schwertmann, U. (eds), Pseudogley and gley-genesis and use of hydromorphic soils. Transactions of Commission V and VI of the International Society of Soil Science, U.S.A.

Schwertmann, U. 1985. The effect of pedogenic environments on iron oxide minerals. In Stwart, E.H. (ed), Advances in Soil Science 1, New York, 171-200.

Schwertmann, U and Fanning, D.S. 1976. Iron-Mn concretions in hydrosequences of soils in loess in Bavana. Soil Science Society of America Journal, New York, 40: 731-738.

Sianu, P.S. and Pundeer, G.S. 1978. Morphology, genesis, and classification of soils of Indo-Gangetic plains In Review of soil research in India II. 12th Interntional Congress of Soil Science, New Delhi, India, 468-473.

Simonson, G.H. and Boersma, L. 1972. Soil morphology and watertable relations: 11. Correlation between annual water-table fluctuations and profile features. Soil Science Society of America Proceedings, New York, 36: 469-653.

Smith, H. and Wilding, L.P. 1972. Genesis of argillic horizons in Ochraqualfs derived from fine textured, till deposits of north-western Ohio and southwestern Michigan. Soil Science Society of America Proceedings, New York, 36: 808 - 815.

Smyth, A.J. and Montgomery, R.F. 1962. Soils and land use in Central Western Nigeria. Government of Western Nigerian Press, Ibadan, Nigeria. 265p.

Soil Conservation Service 1984. Soil Survey Laboratory methods and procedures for collecting soil samples. Soil Survey Investigations Report No 1 (revised edition). USDA, SCS, U.S Government Printing Office, Washington, D.C. 21-63.

Soil Survey Staff, 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agric. Handbook 436, SCSθUSDA, U.S Printing Office, Washington, D.C. 754p.

__________ 1981. New survey manual. Designations for horizons and layers, work draft (430-V) USDA 43θ-V, Government Printing Office, Washington, D.C. 39-51.

________ 1987. Keys to soil taxonomy (third printing) SMSS technical monograph, No. 6, Ithaca, New York, 280p.

Stoops, W.A. 1980. Ion adsorption mechanisms in oxidic soils; implications for point of zero charge determination. Geoderma, Amsterdam, 23: 303-314.

Storie, R.E. 1954. Land classification as used in California for the appraisal of land for taxation purposes. 5th Interntional Congress of Soil Science, Leopoldville Communication, vol. 4, 407-412.

Sudom, M.D. and St. Arnaud, R.J. 1971. Use of quartz, zirconium and titanium as indices in pedological studies. Canadian Journal of Soil Science, Ottawa, 51: 385-396.

Sys, C. and Frankart, F. 1971. Land capability classification in the humid tropics. African Soils, Lagos, vol. XVI No 3, 153-200.

Torrent, J., Schwertmann, U., Fechter, H., and Alferez, F. 1984. Quantitative relationships between soil colour and hematite content. Soil Science, Baltimore, 136: 354-358.

Udo, K.R. 1978. A comprehensive geography of West Africa, Africana Publishing, New York.

Valette, J. 1967. The reconnaisance soil survey of an area near Yelwa and Bin Yauri, Sokoto Province, Northern Nigeria. Soil Survey Bulletin, No 39. Samaru, Institute for Agricultural Research, Ahmadu Bello University, 29p.

Van Diepen, C.A. 1985. Wetland soils of the world, their characterization and distribution in the FAO-Unesco approach. In International Rice Research Institute, Wetland Soils: Characterization and Utilization. Proceedings of a workshop 26 March - 1 April, Los Banos, Philippines. 361-374.

van Ophen, H. 1963. Introduction to clay colloid chemistry. New York, Intersicence Publishers, 18-104.

Van Raij, B, and Peech, M. 1972. Electrochemical properties of some Oxisols and Alfisols of the tropics. Soil Science Society of America Proceedings, New York, 36: 587-593.

van Wallenburg, C. 1973. Hydromorphic soil characteristics in alluvial soils in connection with soil drainage. In Schlichting, E. and Schwertmann, U (eds), Pseudogley and gley-genesis and use of hydromorphic soils. Transactions of Commission V and VI of the International Society of Soil Science, U.S.A.

Veldkamp, W.J. 1979. Land evaluation of valleys in tropical rain area - A case study. Published Ph.D. Thesis. Agricultural University, Wageningen. 266p.

Veneman, P.L.M; Vepraskas, M.J. and Bourman, J. 1976. The physical significance of soil mottling in a Wisconsin toposequence. Geoderma, Amsterdam, 15: 103-118.

Wada, K. 1982. Allophane and imogolite In: Dixon, J.B. and Weed, S.B. (eds), Minerals in soil environments. Soil Science Society of America Inc., Wisconsin, U.S.A., 603-633.

Wakatsuki, T., Ishikawa, I., Araki, S., and Kyuma, K. 1984. Changes in clay mineralogy in a chronosequence of polder paddy soils from Kojima Basin, Japan. Soil Science and Plant Nutrition, Tokyo, 30(1) 25-38.

Wakatsuki, T. and Wielemaker, W.G. 1985. Clay mineralogy of a soil formed in peralkaline volcanic ash from the great rift valley in Kenya. Soil Science and Plant Nutrition, Tokyo, 31(3): 475-480.

White, F. 1983. Unesco/AETFAT/UNSO Vegetation map of Africa. Unesco, Paris. 356pp + map.

Whitting, L.D. 1965. X-ray diffraction techniques for mineral identification and mineral composition. In Black, C.A. (ed), Methods of soil analysis, part 1. Agronomy 9: 674-687. American Society of Agronomy Inc., Madison, Wisconsin, U.S.A.

Yaalon, D.H. and Kalmar, D. 1978. Dynamics of cracking and swelling clay soils: Displacement of skeletal grains, optimum depth of slickensides, and rate of intrapedonicturbation. Earth Surface Processes 3: 31-42.

Young, A. 1976. Tropical soils and soil survey. Cambridge. University Press. 468p.

Zi-Tong, G. 1983. Pedogenesis of paddy soil and its significance in soil classification. Soil Science Baltimore, 135(1): 5-10.

APPENDICES

APPENDIX A

DETAILED SOIL PROFILE DESCRIPTION

Makurdi transect

Profile Number: MD1

Soil Name: Santigi series

Higher Category Classification: Typic Ustifluvent

Date of Examination: June 20, 1987

Author of Description: G.O. Oyediran

Location: About 500 metres from Benue river Lower Benue River and Rural development Authority, rice field near Otave village, 11 kilometres west of Makurdi (approximately 7°45'N, 8°30'E), Benue State of Nigeria.

Elevation: 80 metres above sea level

Landform

(i) Physiographic position of the site: levee

(ii) Topography of surrounding country: flat

(iii) Microtopography: Nil

Slope on which profile is sited: $<1.0\%$

Vegetation and Land-use: Grasses; seasonally used for swamp rice cultivation.

Climate: Hot subhumid tropical. Mean annual rainfall is about 1400mm with a relatively weak bimodal distribution pattern. Mean mid-day air temperature is approximately 27°C.

Parent Material: Alluvial deposit

Drainage: Somewhat poorly drained

Moisture condition in profile: Moist throughout

Depth of groundwater table: Below 168cm by the time of examination.

Presence of surface stones, rock outcrops: none

Evidence of erosion: none

Presence of salt or alkali: none

Human influence; Seasonally used for swamp rice cultivation.

A_{p1} 0-24cm. Dark brown (7.5YR 4/2) moist; clay loam; moderate medium subangular blocky; friable, moist, sticky and plastic wet; few fine grass roots; gradual smooth boundary.

A_2 24-59cm. Dark brown (7.YR 4/4) moist; sandy clay loam; moderate medium granular; friable moist, slightly sticky slightly plastic wet; clear smooth boundary.

$2BA_1$ 59-87cm. Reddish brown (5YR 5/4) moist, loamy sand; moderate medium subangular blocky; friable moist, nonsticky nonplastic wet; clear wavy bouddary.

$2BA_2$ 87-120cm. Brown (7.5YR 5/4) moist; loamy sand; moderate medium subangular blocky; friable moist, nonsticky nonplastic wet; clear smooth boundary.

2BC 120-168cm. Reddish brown (5YR 4/3) moist; sandy clay loam; moderate medium subanguar blocky; friable moist, nonsticky nonplastic wet.

Profile Number MD2

Soil Name: Iju series

Higher Category Classification: Typic Udifluvent

Date of Examination: June 20, 1987

Location: About 1.0 kilometre from Benue river (ie 500 metres from profile MD1).

Landform

(i) Physiography: Levee/backswamp transition

(ii) Topography: flat

Vegetation or Land-use: Grasses, seasonally used for swamp rice cultivation.

Parent Material: Alluvial deposit

Drainage: Somewhat poorly drained

Moisture condition in profile: Moist throughout

Depth of groundwater table: Slightly below 171cm dep depth by the time of examination.

A 0-25cm. Dark reddish brown (5YR 3/2) moist; clay; moderate fine and medium granular; friable moist slightly sticky slightly plastic wet; many fine and medium roots; clear smooth boundary.

BA 25-60cm. Dark brown (7.5YR 4/4) moist; clay; moderate medium subangular blocky; friable moist, sticky and plastic wet; clear smooth boundary.

Bw_1 60-97cm. Reddish brown (5YR 4/4 moist);clay moderate medium and strong coarse angular blocky; firm moist; very sticky and very p plastic wet; clear wavy boundary.

Bw_2 97-130cm. Pinkish gray (7.5YR 6/2) moist, with common medium faint brown (7.5YR 5/4) mottles clay; moderate medium subangular blocky; friable moist, sticky and plastic wet,clear smooth boundary.

BC 130-171cm. Brown (10YR 5/3) matrix with common distinct medium dark grayish brown (10YR 4/2) mottles; clay; moderate fine and medium subangular blocky; friable moist, sticky and plastic wet.

Profile Number: MD3

Soil Name: Edoshigi series

Higher Category Classification: Andaqueptic Fluvaquent

Date of Examination: June 20, 1987

Location: 2.0 kilometres from Benue river (ie about 1000 metres from profile MD2).

Landform

(i) Physiography: backswamp

(ii) Topography: almost flat

Vegetation or Land-use: Grasses, seasonally used for swamp rice vultivation.

Parent material: Alluvial deposit

Drainage: Seasonally flooded

Moisture condition in profile: Moist from surface to 45cm depth, but wet below.

Depth of groundwater table: About 82cm by the time of examination.

A 0-30cm. Very dark gray (2.5Y3/0) moist; clay; moderate fine and medium subangular blocky; firm moist, slightly sticky and plastic wet; few fine roots; clear smooth boundary.

BA 30-45cm. Gray (10YR 6/1) moist, with many medium distinct dark reddish gray (5YR 4/2) mottles; clay; moderate medium subangular blocky; very firm moist, sticky and plastic wet; gradual smooth boundary.

$2Bw_1$ 45-70cm. Gray (10YR 6/1) wet, with common medium distinct reddish brown (5YR 5/4) mottles; clay; moederate medium and strong coarse angular blocky; very sticky and very plastic wet; clear wavy boundary.

$2Bw_2$ 70-113cm. Reddish gray (5YR 5/2) wet, with few fine faint brown (7.5YR 5/4) mottles; clay; moderate medium and coarse angular blocky; very sticky and very plastic wet; clear smooth boundary.

2BCg 113 - 182cm. Pinkish gray (7.5YR 6/2) wet, with few fine faint brown (7.5YR 5/4) mottles; clay; moderate medium angular blocky; sticky and plastic wet.

Profile Number: MD4

Soil Name: Edoshigi series

Higher Category Classification: Aquic Kandiustult

Date of Examination: June 20, 1987

Location: About 3.3 kilometres from Benue river (i.e 1.3km. from MD3).

Landform

(i) Physiography: backswamp/upland transition

(ii) Topography: almost flat

Vegetation or Land-use: Grasses and some few shrubs; seasonally used fof swamp rice cultivation.

Parent Material: Alluvial deposit

Drainage: Seasonally flooded

Moisture condition in profile: Moist from surface to 128cm depth, but wet below.

Depth of groundwater table: About 137cm by the time of examination.

A 0-22cm Black (7.5YR 2/0) moist; clay; moderate medium granular; friable moist; slightly sticky slightly plastic wet; many fine grass roots; clear smooth boundary.

BA 22-64cm. Dark gray (5YR 4/1) moist, with few fine faint strong brown (7.5YR 5/8) mottles; clay; moderate medium subangular blocky; firm moist, sticky and plastic wet; clear smooth boundary.

Bwc_1 64-90cm. Very dark gray (7.5YR 3/0) moist with few fine distinct reddish yellow (7.5YR 6/8) mottles; clay; moderate medium and strong coarse angular blocky; very firm moist, very sticky very plastic wet; few soft spherical dark-red sesquioxidic nodules/concretions, clear wavy boundary.

Bwc_2 90-128cm. Reddish gray (5YR 5/2) moist, with many medium and coarse prominent brown (7.5YR 5/4) mottles; clay; strong medium and coarse angular blocky; very firm moist, very sticky very plastic wet; many soft spherical dark-red sesquioxidic nodules/concretions; clear smooth boundary.

Bcg 128-185cm. Gray (5YR 5/1) wet, with many medium prominent yellowish red (5YR 5/8) mottles; clay; strong coarse angular blocky; very sticky and very plastic wet.

Profile Number: MD5

Soil Name: Timfun series

Higher Category Classification: Typic Kandiustalf

Date of Examination: June 20, 1987

Location: 3.8 kilometres from Benue River (ie 280 metres from MD4).

Landform.

(i) Physiography: Upland, middle - slope

(ii) Topography: Undulating

Slope on which profile is sited: 2.5%

Vegetation or Land-Use: Grasses, shrubs and few trees

Parent Material: Colluvial material

Drainage: Fairly well-drained

Moisture condition in profile: Moist throughout

Depth of groundwater table: Well below 185cm

A 0-26cm. Dark brown (7.5YR 4/2) moist; loam; moderate medium granular; friable moist, slightly sticky slightly plastic wet; many fine and few medium roots; gradual smooth boundary.

BA 26-59cm. Brown (7.5YR 5/4) moist, clay loam, moderate medium subangular blocky; friable moist, sticky and plastic wet; few very fine roots; clear smooth boundary.

Bt_1 59-80cm. Yellowish red (5YR 4/6) moist, with few medium faint reddish yellow (7.5YR 6/8) mottles clay; mederate medium subangular blocky; friable moist, sticky and plastic wet; clear smooth boundary.

Bt_2 80-124cm. Yellowish red (5YR 5/6) moist, with common medium distinct gray (5YR 5/1) mottles;

clay; strong medium and coarse angular blocky; firm moist, very sticky very plastic wet; clear wavy boundary.

C 124-185cm. Red (2.5YR 4/8) moist, with many coarse distinct gray (5YR 5/1) mottles; clay; moderate medium subangular blocky; friable moist, sticky and plastic wet.

Gadza transect

Profile Number: GZ1

Soil Name: Ishaga series

Higher Category classification: Typic Tropaquept

Date of Examination: June 11, 1987

Author of Description: G.O. Oyediran

Location: About 55 metres from Gadza river. Gadza valley, 6.8 kilometres south of Bida (approximately 9°10'N, 5°58'E) off Bida Federal Polythechnica road, Niger State of Nigeria.

Elevation: 96 metres above sea level

Landform

(i) Physiographic position of the state:

Valley lowland

(ii) Topography of surrounding country:
Almost flat

(iii) Microtopography: Nil

Slope on which profile is sited: 1.1%

Vegetation and Land-use: Bush fallow, predominantly grasses; seasonally used for swamp rice cultivation and dry season cropping (vegetables and cowpea).

Climate: Hot subhumid tropical with marked wet and dry seasons. Mean annual rainfall is about 1175mm. Mean mid-day air temperature is approximately 27°C.

Parent Material: Alluval deposit

Drainage: Somewhat poortly drained.

Moisture condition in profile: Moist from surface to 129cm, but wet below.

Depth of groundwater table: Below 192cm by the time of examination.

Presence of surface stones, rock outcrops: none

Evidence of erosion: None

Human influence: Seasonally used for swamp rice cultivation in the rainy season.

A 0-21cm. Dark brown (7,5YR 4/2) moist sandy, loaml weak find granular; friable moist; nonsticky nonplastic wet; many medium roots; clear wavy boundary.

BA 21-52cm. Brown (7.5YR 5/2) moist, with few fine faint strong brown (7.5YR)5/6) mottles; sandy loam; moderate fine and medium subangular blocky; friable moist, nonsticky nonplastic wet; few fine roots; clear smooth boundary.

Bw 52-95cm. Brown (7.5YR 5/2) moist; loam; moderate fine subangular blocky; friable moist; nonsticky monplastic wet; clear msmooth boundary.

BC 95-129cm. Light brownish gray (10YR 6/2) moist, with common fine distinct strong brown (7.5YR 5/6) mottles; sandy loam; strong medium subangular blocky; friable moist, nonsticky nonplastic wet; clear smooth boundary.

Cg 129-192cm. Light brownish gray (10YR 6/2) wet with many fine prominent strong brown (7.5YR 5/8) mottles; sandy loam; strong medium subangular blocky; firm moist, monsticky nonplastic wet.

Profile Number: GZ2

Soil Name: Mesan series

Higher Category Classification: Typic Tropaquept

Date of Examination: June 11, 1987

Location: 147 metres from profile GZ1

Landform

(i) Physiography: Valley bottom

(ii) Topography: Almost flat

Slope on which profile is sited: 1.0%

Vegetation and Land-use: Under savanna fallow regrowth at time of examination. Seasonally used for swamp rice cultivation.

Parent Material: Alluvial deposit

Drainage: Seasonally flooded

Moisture condition in profile: Moist from surface to 60cm, but wet below by the time of examination.

Depth of groundwater table: About 110cm by the time of examination.

Ap 0 - 11cm. Grayish brown (10YR 5/2) moist, sandy loam moderate fine granular; friable moist; nonsticky nonplastic wet; many medium roots;

gradual smooth boundary.

AB$_1$ 11-32cm. Light brownish gray (10YR 6/2) moist; coarse sand; moderate medium granular; friable moist, nonsticky nonplastic wet; few fine roots; gradual smooth boundary.

AB$_2$ 32-60cm. Light brownish gray (10YR 6/2) moist; sand; moderate medium subangular blocky; friable moist, nonsticky nonplastic wet; clear wavy boundary.

2BA 60-110cm. Grayish brown (10YR 5/2) wet, brown (10YR 5/3) moist; sandy loam; strong medium subangular blocky; slightly stricky slightly plastic wet, friable moist, hard dry; clear smooth boundary.

2Cg 110cm - 168cm. Light brownish gray (10YR 6/2) wet; gray (5YR 5/1) moist; coarse sand; moderate medium subangular blocky; nonsticky nonplastic wet, friable moist and slightly hard dry.

Profile Number: GZ3

Soil Name: Indaloke series

Higher Category Classification: Typic Tropaquept

Date of Examination: July 28, 1987

Location: 438 metres from profile GZ2 upslope

Landform

(i) Physiography: Valley bottom/fringe

(ii) Topography: Undulating

Slope on which profile is sited: 1.8%

Vegetation or Land-use: Cassava; seasonally used for swamp rice cultivation.

Parent Material: Alluvial deposit

Drainage: Seasonally swampy

Moisture condition in profile: Moist from surface to 185cm, but wet below.

Depth of groundwater table: About 192 cm by the time of examination.

A 0-18cm. Gray (10YR 6/1) moist, loamy coarse sand; moderate fine and medium granular; friable moist, slightly sticky slightly plastic wet; many medium cassava roots; clear smooth boundary.

AB_1 18-55cm. Light brownish gray (10YR 6/2) moist, with few fine faint strong brown (7.5YR 5/6) mottles; loamy sand; moderate medium granular, friable moist, nonsticky nonplastic wet; common medium cassava roots; clear smooth boundary.

AB_2 55-96cm. Grayish brown (10YR 5/2) moist, with common medium distinct strong brown (7.5YR 5/6) mottles; sandy loam; moderate medium subangular blocky; friable moist, nonsticky nonplastic wet; clear wavy boundary.

$2BA_1$ 96-111cm. Dark gray (10YR 4/1) moist, with common medium faint strong brown (7.5YR 5/6) mottles; loamy coarse sand; strong medium angular blocky; firm moist, sticky and plastic wet; clear wavy boundary.

$2BA_2$ 111-136cm. Gray (10YR 5/1) moist, sand; moderate medium subangular blocky friable moist, nonsticky nonplastic wet; clear smooth boundary

2BC 136-151cm. Dark gray (10YR 4/1) moist; lomay sand; stong medium angular blocky; firm moist, sticky and plastic wet; clear smooth boundary.

2C 151-192cm. Gray (10YR 6/1) wet, Light brownish gray (10YR 6/2) moist; loam sand; Light moderate medium subangular blocky; nonsticky nonplastic wet, friable moist, soft dry.

Profile Number: GZ4

Soil Name: Ishaga series?

Higher Category Classification: Aquic Quartzipsamment.

Date of Examination: July 28, 1987

Location: About 560 metres from profile GZ3 upslope

Landform

(i) Physiography: Valley fringe

(ii) Topography: Undulating

Slope on which profile is sited: 2.5%

Vegetation or Land-use: Shrubs, grasses and few sheabutter (Vitellaria paradoxa) and oil palm (Elaesis guinensis) tress.

Parent Material: Colluvial/Alluvial materials

Draingag: Somewhat poorly-drained

Moisture condition in profile: Moist throughout the profile by the time of examination.

Depth of groundwater table: Below 192cm.

Ap 0-20cm Dark brown (7.5YR 4/2) moist; slightly gravelly loamy coarse sand; weak medium granular friable moist, nonsticky nonplastic wet; few medium roots; gradual smooth boundary.

AB_1 20-40cm. Strong brown (7.5YR 5/6) moist; loamy coarse sand; moderate medium subangular blocky; friable moist, nonsticky nonplastic wet; few medium roots; clear smooth boundary.

AB_2 40-60cm. Strong brown (7.5YR 5/6) moist, with few fine faint yellowish brown (10YR 5/8) mottles; loamy coarse sand; moderate medium subangular blocky; friable moist, slightly sticky slightly plastic wet; few fine roots; clear wavy boundary.

BA 60-93cm. Yellowish brown (10YR 5/8) moist, with common medium distinct reddish brown (2.5YR 5/4) mottles; loamy coarse sand; moderate medium and coarse subangular blocky; firm moist, sticky and plastic wet; clear smooth boundary.

BC_1 93-169cm. Very pale brown (10YR 7/4) moist; loamy coarse sand; few rounded ironstone pebbles and boulders (10-30cm); moderate medium and coarse subangular blocky; firm moist, sticky and plastic wet; clear smooth boundary.

BCrg2 169-192cm. Reddish Yellow (7.5YR 6/6) moist, with many medium distinct pinkish white (7.5YR 8/2) mottles; coarse sandy loam; a discontinuous layer of fairly weathered ironstone; moderate medium subangular blocky; firm moist, sticky and plastic wet.

Profile Number: GZ5

Soil Name: Kulfo series

Higher Category Classification: Typic Kandistult

Date of Examination: July 29, 1987

Location: About 800 metres from profile GZ4 upslope

Elevation: 108 metres above sea level

Landform

(i) Physiography: Upland, middle-slope

(ii) Topography: Undulating

(iii) Micrctopography: termite mounds

Slope on which profile is sited: 4.0%

Vegetation or Land-use: Bush regrowth, seasonally used for sorghum/maize/mellon/cowpea cultivation.

Parent Material: Colluvial materials

Drainage: Well-drained

Moisture condition in profile: Moist throughout

Depth of Groundwater table: Well below 207cm.

A 0-14cm. Darm brown (7.5YR 4/4) moist; loamy coarse sand, moderate fine crumb, friable moist, nonsticky nonplastic wet; common fine roots; gradual smooth boundary.

AB 14 - 37cm. Reddish brown (5YR 4/4) moist; coarse sandy loam; moderate medium subangular blocky; friable moist, slightly sticky slightly plastic wet; few medium and coarse roots; clear smooth boundary.

BA 37 - 92cm. Yellowish red (5YR 4/6) moist; very fine sandy loam; moderate to strong medium subangular blocky; friable moist, sticky and plastic wet; few fine roots; gradual smooth boundary.

$2B_{t1}$ 92 - 140cm. Red (2.5YR 5/6) moist; slightly gravelly sandy clay; strong medium and coarse subangular blocky; friable moist, sticky and plastic wet; diffuse smooth boundary.

$2B_{t2}$ 140 - 182cm. Red (2.5YR 5/6) moist; sandy clay; many rounded gravels and boulders (3-25cm); strong medium and coarse subangular blocky; thin void cutans; friable moist, sticky and plastic wet; few spherical black Fe/Mn concretions, clear smooth boundary.

2C 182 - 207cm. Red (2.5YR 5/6) moist, with many medium prominent reddish yellow (5YR 7/6) mottles, gravelly sandy clay; moderate medium subangular blocky; friable moist, slightly sticky slightly plastic wet.

Profile Number: GZ6

Soil Name: Alagba series

Higher Category Classification: Typic Kandiustült.

Date of Examination: July 29, 1987

Location: 305 metres off Bida Federal Polytechnic road; near Gbamsitako village.

Elevation: 130 metres above seal level

Land form

(i) Physiography: Upper slope/summit

(ii) Topography: Undulating

(iii) Microtopography: Nil

Slope on which profile is sited: 5.3%

Vegetation or Land-use: Predominantly grasses and few sheabutter (Vitellaria paradoxa) trees; used for upland crops (maize/sorghum/mellon) production in the rainy season.

Parent material: Colluvial materials

Drainage: Well-drained

Moisture condition in profile: Moist throughout

Depth of groundwater table: Below 200cm.

A 0-24cm. Dark brown (7.5YR 4/4) moist; loamy sand; moderate fine granular; friable moist nonstickly nonplastiv wet; few medium roots; clear smooth boundary.

AB 24-59cm. Reddish brown (5YR 5/4) moist, very fine sandy loam; moderate medium subanguar blocky; friable moist, slightly sticky slightly plastic wet; few fine roots; gradual smooth boundary.

$2B_{t1}$ 59-97cm. Yellowish red (5YR 5/6) moist; sandy clay; moderate medium subangular blocky; friable moist, slightly sticky slightly plastic wet; few fine roots; gradual smooth boundary.

2Bct2 97-160cm. Yellowish red (5YR 5/6) moist; sandy clay; strong medium subangular blocky; thin void cutans; firm moist, sticky and plastic wet; few medium sheabutter roots; few spherical black Fe/Mn concretions; clear smooth boundary.

2C 160-290cm. Yellowish red (5YR 5/6) moist; sandy clay; many ironstone gravels and boulders (3-35cm); moderate medium subangular blocky; friable moist; slightly sticky slightly plastic wet.

Dwam transect

Profile Number: DM1

Soil Name: Gbajigi series

Higher Category Classification: Tropaquent

Date of Examination: November 27, 1987

Author of Description: G.O. Oyediran

Location: New Federal Ministry of Agric. Dwam irrigation project site; 53 kolometres from Yola, off Yola-Gombe road (9^{o} 10'N 12^{o}14'E). About 500 metres from Benue river.

Elevation: 150 metres above sea level

Landform:

(i) Physiographic position of the site: levee/ backswamp

(ii) Topography of surrounding country: Almost flat

(iii) Microtopography: Nil

Slope on which profile is sited: 0.8%

Vegetation and Land-use: Grasses; close to the profile pit is a sorghum plot at the time of examination.

Climate: Hot subhumid tropical. Mean annual rainfall is about 850cm. Rainfall pattern indicate a unimodal trend. Mean mid-day air temperature is approximately $28^{o}C$.

Parent Material: Alluvial deposit

Drainage: Poorly drained

Moisture condition in profile: Moist from surface to 103cm, but wet below.

Depth of groundwater table: Below 179cm. by the time of examination.

Presence of surface stones, rock outcrops: none

Evidence of erosion: none

Presence of salt or alkali: none

Human influence: Occasionally used for maize/sorghum cultivation.

A 0-25cm. Dark brown (7.5YR 4/2) moist; silty clay; moderate medium subangular blocky; very spongy moist, slightly sticky slightly plastic wet; common fine grass roots; clear smooth boundary.

BAc 25-44cm. Brown (7.5YR 5/2) moist, with few fine faint yellowish brown (10YR 5/8) mottles; silty clay; weak medium subangular blocky; very friable moist, slightly sticky slightly plastic wet; few small hard spherical black Fe/Mn concretions; gradual smooth boundary.

Bwc_1 44-72cm. Dark brown (7.5YR 4/2) moist, with common medium distinct reddish brown (5YR 5/4) mottles; silty clay; weak medium subangular blocky; friable moist, sticky and plastic wet; frequent small hard spherical black Fe/Mn concretions; diffuse smooth boundary.

$2Bwc_2$ 72-103cm. Dark brown (7.5YR 4/2) moist, with common medium distinct reddish brown (5YR 5/4) mottles; loam; weak medium subangular blocky; friable moist, sticky and plastic wet; very freequent small hard spherical black sesquioxidic concretions; clear smooth boundary.

$2Bwc_3$ 103-135cm. Gray (5YR 5/1) moist, with common medium prominentreddish yellow (5YR 6/8) and very dark brown (10YR 5/2) mottles; sandy clay loam; weak medium subangular blocky; friable moist, sticky and plastic wet; very frequent small hard spherical black sesquioxidic concretions; abrupt smooth boundary.

2C 135-179cm. Pinkish gray (7.5YR 6/2) moist, with many coarse distinct stpong bpown (7.5YR 5/6) mottles; loamy coarse sand; weak fine subangular blocky; very friable moist; nonsticky nonplastic wet.

Profile Number: DM2

Soil Name: Boskeri series

Higher Category Classification: Udic Chromustert

Date of Examination: November 27, 1987

Location: 1100 metres from profile DM1

Landform:

(i) Physiography: depression

(ii) Topography: Undulating

Slope on which profile is sited: 2.2%

Vegetation and Land-use: Grasses and some shrubs; used for grazing.

Parent Material: Formed in shale dominated parent materials.

Drainage: Somewhat poorly-drained

Moisture condition in profile: Moist throughout

Depth of groundwater table: Well below 165cm.

Evidence of erosion: None, but common medium cracks (about 3cm wide and 28cm deep).

A 0-20cm. Dark yellowish brown (10YR 3/4) moist, with few very faint gray mottles; clay; moderate medium subangular blocky; very hard dry, firm moist, very sticky very plastic wet; common medium cracks (about 3cm. wide) ; common fine rass roots; clear irregular boundary.

AB 20-42cm. Dark yellowish brown (10YR 3/4) moist, with few very faint grey mottles; clay; moderate medium angular blocky; very fine (about 1.5cm wide) cracks; few fine roots, clear smooth boundary.

Bw_1 42-74cm. Dark grayish brown (10YR 4/2) moist, with common medium distinct yellowish brown (10YR 5/8) mottles; clay; moderate medium angular blocky; very hard dry, very firm moist, very sticky very plastic wet; few fine roots; slickensides; gradual smooth boundary.

Bw_2 74-109cm. Light brownish gray (10YR 6/2) moist, with common medium faint yellowish brown (10YR 5/8) mottles; slightly gravelly clay; moderate medium angular blocky; very hard dry, very firm moist, very sticky very plastic wet; slickensides; clear smooth boundary.

BC 109-165cm. Gray (10YR 5/1) moist, with common medium faint brown (10YR 5/3) mottles; very grvaelly clay ; moderate medium subanguar blocky;

many medium spherical quartz gravel; hard dry, firm firm moist, sticky and plastic wet.

Profile Number: DM3

Soil Name: Ashaka series

Higher Category Classification: Typic Kandiustalf

Date of Examination: November 27, 1987

Location: 1.0 kilometre from profile DM2 upslope

Elevation: 162 metres above sea level

Landform

(i) Physiography: Upland, upper-slope/summit

(ii) Topography: Udulating

Slppe on which profile is sited: 4.4%

Vegetation and Land-use: Grasses and few shrubs; used for growing sorghum in rainy season.

Parent Material: Colluvial materials on limestone

Drainage: Well drained

Moisture condition in profile: Moist throughout

Depth of groundwater table: Well below 175cm

A 0-18cm. Dark brown (7.5YR 4/2) moist, with few fine very faint yellowish mottles; slightly gravelly sandy clay loam; moderate medium subangular blocky; hard dry, firm moist, slightly sticky slightly plastic wet; common fine grass roots; gradual smooth boundary.

AB 18-43cm. Yellowish brown (10YR 5/4) moist, with few fine very faint gray mottles; slightly gravelly clay; moderate medium subangular blocky; slightly hard dry friable moist, slightly sticky slightly plastic wet; few fine grass roots; gradual smooth boundary.

Bt1 43-76cm. Yellowish brown (10YR 5/6) moist; slightly gravelly sandy clay loam; moderate medium angular blocky; hard dry, firm moist, sticky and plastic wet; clear smooth boundary.

2Bt2 76-120cm. Yellowish brown (10YR 5/6) moist, very gravelly clay; moderate medium angular blocky, very hard dry, firm moist, sticky and plastic wet; many medium spherical quartz gravel, few angular quartz stones (8-10cm); clear smooth boundary.

2C 120-160cm. Brownish yellow (10YR 6/8) moist; very gravelly sandy clay loam; moderate fine subangular blocky; hard dry, firm moist, slightly sticky slightly plastic wet; few medium spherical quartz gravel, many angular quartz stones; clear wavy boundary.

R 160-175cm+. Slightly weathered limestone (rock); sandy clay loam; massive; strong effervescence with 10% HCl.

Argungu transect

Profile Number: AR1

Soil Name: Tsantsaga series.

Higher Category Classification: Andaqueptic Fluvaquent

Date of Examination: December 14, 1987

Author of Description: G.O. Oyediran

Location: About 1.0km from the bridge on Sokoto river at Argungu (approximately 12°50'N 4°30'E), Sokoto State of Nigeria.

Elevation: 200 metres above sea level

Landform:

(i) Physiographic position of the site: Proximal levee

(ii) Topography of surrounding country: Almost flat

(iii) Microtopography: Nil

Slope on which profile is sited: 0.8%

Vegetation and Land-use: Grasses; used for long-straw rice (*Oryza glaberima*) cultivation.

Climate: Hot subhumid tropical. Mean annual rainfall is about 650mm with a unimodal pattern of distribution. The rainy season is followed by short dry season and then harmattan period. Mean mid-day air temperature is approximately 28°C.

Parent Material: Alluvial deposit

Drainage: Poorly-drained

Moisture condition in profile: Moist throughout.

Depth of groundwater table: Below 173cm by the time of examination.

Presence of surface stones, rock outcrops: none

Evidence of erosion: none

Presence of salt or alkali: none

Human influence: seasonally for swamp rice cultivation.

A 0-35cm. Grayish brown (10YR 5/2) moist; with common medium distinct strong brown (7.5YR 5/8) mottles; clay; moderate medium subangular blocky; firm moist, stickly and plastic wet; common small hard spherical black sesquioxidic modules/concretions; common fine roots; abrupt smooth boundary.

AB_1 35-61cm. Light brownish gray (10YR 6/2) moist with common coarse distinct brownish yellow (10YR 6/6) mottles; clay loam; moderate fine subangular blocky; friable moist slightly sticky slightly plastic wet; gradual smooth boundary.

$2AB_2$ 61-101cm. Very pale brown (10YR 7/3) moist, with common coarse distinct yellow (1oYR 7/6) mottles; very fine sandy loam; weak fine subangular blocky; very friable moist, nonstickly nonplastic wet; clear smooth boundary.

$2Bwcg_1$ 101-128cm. Light brownish gray (10YR 6/2) moist, with common coarse distinct brownish yellow (10YR 6/6) mottles; loamy coarse sand, weak fine subangular blocky; friable moist, nonstick nonplastic wet; common small hard spherical black and orange sesquioxidic nodules/concretions; abrupt smooth boundary.

$2Bwcg_2$ 128-157cm. Light brownish gray (10YR 6/2) moist, with many coarse prominent yellowish brown (10YR 5/8) mottles; coarse sandy loam; weak fine subangular blocky; friable moist, nonsticky nonplastic wet; common small hard spherical black manganese/iron nodules and concretions; abrupt smooth boundary.

$2BCg_1$ 157-173cm. Brown (10YR 5/3) moist, with common coarse distinct yellowish brown (10YR 5/4) mottles, coarse sandy loam; weak fine ubangular blocky; friable moist, nonsticky nonplastic wet; abrupt smooth boundary.

$2BCG_2$ 173cm+ Grayish brown (10YR 5/2) moist, with common medium distinct yellowish brown (10YR 5/8) mottles; loamy coarse sand; moderate medium to coarse angular blocky; friable moist, nonsticky nonplastic.

Profile Number: AR2

Soil Name: Sirti series

Higher Category Classification: Andaqueptic Fluvaquent

Date of Examination: December 14, 1987

Location: About 800 metres from profile AR1 (i.e 1.8km. from the bridge).

Elevation: 200 metres above sea level

Landform

(i) Physiography: Levee/backswamp

(ii) Topography: flat

Vegetation and Land-use: Grasses; used for white short-straw rice (Oryza glaberima) cultivation.

Parent Material: Alluvial deposit

Drainage: Poorly drained

Moisture condition in profile: Moist throughout.

Depth of groundwater table: Below 179cm.

A 0-24cm. Dark yellowish brown (10YR 3/4) moist, clay; moderate fine subangular blocky; friable moist, slightly sticky slightly plastic, common fine roots; clear smooth boundary.

Bw_1 24-50cm. Brown (10YR 5/3) moist, with common medium distinct yellowish brown (10YR 5/8) mottles; clay; moderate medium angular blocky; firm moist, sticky and plastic wet; gradual smooth boundary.

$2Bw_2$ 50-77cm. Brown (10YR 5/3) moist, with many medium distinct yellowish brown (10YR 5/8) mottles, sandy clay loam; weak medium angular blocky; friable moist, slightly sticky slightly plastic; diffuse smooth boundary.

$2BC_1$ 77-110cm. Pale brown (10YR 6/3) moist, with many medium distinct yellowish brown (10YR 5/8) mottles; loamy sand; weak medium subangular blocky; friable moist, slightly sticky slightly plastic; abrupt smooth boundary.

$2BC_2$ 110-179cm. Yellow (10YR 7/6) moist, with many coarse distinct brownish yellow (10YR 6/8) mottles; sand; weak fine subangular blocky; very friable moist, nonsticky nonplastic wet.

Profile Number: AR3

Soil Name: Shen series

Higher Category Classification: Tropaquent

Date of Examination: December 14, 1987

Location: About 1.0km from profile AR2 (i.e 2.8km from the bridge).

Elevation: 200 metres above sea level

Landform

(i) Physiography: backswamp

(ii) Topography: Almost flat

Vegetation and Landuse - Almost bareland; few wild rice.

Parent material: Alluvial deposit

Drainage: Seasonally swampy

Moisture condition in profile: Moist throughout.

Depth of groundwater table: Below 194cm by the time of examination.

A 0-31cm. Dark grayish brown (10YR 4/2) moist; clay; moderate to strong coarse angular blocky; firm moist, sticky and plastic wet; few fine roots; clear smooth boundary.

BA 31-58cm. Dark grayish brown (10YR 4/2) moist, clay; strong very coarse angular blocky; firm moist, very sticky very plastic wet; diffue smooth boundary.

Bw_1 58-85cm. Light brownish gray (10YR 6/2) moist, with few fine faint brown (10YR 5/3) mottles; clay; strong very coarse angular blocky to massive; very firm moist, very sticky very plastic wet; abrupt smooth boundary.

$2Bwcg_2$ 85-118cm. Light brownish gray (10YR 7/2) moist, with common medium distinct yellow (10YR 7/6) mottles; sandy clay loam; moderate medium subangular blocky; friable moist, slightly sticky slightly plastic wet; many small hard spherical black Mn/Fe nodules and concretions; gradual smooth boundary.

2Bwcg$_3$ 118-160cm. Light gray (10YR 7/2) moist, with common medium distinct brownish yellow (10YR 6/8) mottles; loam; moderate medium subangular blocky; friable moist, slightly sticky slightly plastic wet; common small hard spherical black Mn/Fe nodules and concretions; clear smooth boundary.

2BC 160-194cm. Brownish yellow (10YR 6/8) moist; loamy coarse sand; weak medium subangular blocky; very friable moist, nonsticky nonplastic wet.

Profile Number: AR4

Soil Name: Barriki series

Higher Category Classification: Andic Haplumbrept

Date of Examination: December 16, 1987

Location: About 800 metres from profile AR3 (i.e 3.6km from the bridge).

Landform

(i) Physiography: Distal (natural) levee

(ii) Topography: Almost flat

Vegetation and Land-use: 'Chiwaka' grasses and scattered shrubs.

Parent Material: Alluvial deposit

Drainage: Somewhat poorly-drained

Moisture condition in profile: Moist throughout

Depth of groundwater table: Well below 170cm.

A 0-18cm. Dark yellowish brown (10YR 4/4) moist, with few medium distinct strong brown (7.5YR 5/6) mottles; fine sandy loam, weak medium subangular blocky; friable moist, slightly sticky slightly plastic wet; few fine roots; clear wavy boundary.

Bw 18-50cm. Pale brown (10YR 6/3) moist, with many medium prominent yellowish red (5YR 4/6) mottles; sany clay loam; weak coarse subangular blocky; friable moist, slightly sticky slightly plastic wet; few medium roots; clear irregular boundary.

BC 50-85cm. Pale brown (10YR 6/3) moist, with many coarse prominent strong brown(7.5YR 5/6) mottles; loamy coarse sand, weak fine subangular blocky; friable moist, nonsticky nonplastic wet; clear smooth boundary.

C 85-170cm+ Very pale brown (10YR 7/4) moist, with common coarse distinct reddish yellow (7.5YR 6/6) mottles; coarse sand; weak very fine subangular blocky; very friable moist, nonsticky nonplastic wet.

Profile Number: AR5

Soil Name: Angwan series

Higher Category Classification: Albaquic Paleudalf

Date of Examination: December 16, 1987

Location: About 3.4km. from profile AR4 (i.e 7.0km from the bridge).

Landform

(i) Physiography: Depression between the old levee andupland.

(ii) Topography: Undulating

Vegetation and Land-use: Grasses; used for short straw (white) rice (Oryza glaberima) cultivation.

Parent Material: Alluvial depost

Drainage: Poorly-drained

Moisture condition in profile: Moist from surface to 140cm, but wet below.

Depth of groundwater table: About 160cm by the time of examination.

A 0-21cm. Dark yellowish brown (10YR 3/4) moist, with common fine distinct yellowish brown (10YR 5/8) mottles; sandy clay loam; moderate medium sub-angular blocky; friable moist, slightly sticky slightly plastic wet; many fine roots; clear smooth boundary.

BA 21-40cm. Dark brown (10YR 4/3) moist, with common medium distinct dark yellowish brown (10YR 4/4) mottles; sandy clay; moderate medium subangular blocky; firm moist, sticky and plastic wet; clear wavy boundary.

Bt_1 40-71cm. Grayish brown (10YR 5/2) moist, with common medium distinct yellowish brown (10YR 5/6) mottles; clay; weak medium angular blocky; firm moist, very sticky very plastic wet; gradual smooth boundary.

Bt_2 71-110cm. Pale brown (10YR 6/3) moist, with common medium distinct yellowish brown (10YR 5/6) mottles; clay; weak medium angular blocky to massive; firm moist, very sticky very plastic wet; abrupt wavy boundary.

BCg 110-140cm. Very pale brown (10YR 7/4) moist, with common coarse prominent yellowish brown (10YR 5/8) mottles; loam; weak fine subangular blocky; friable moist; nonsticky nonplastic wet; clear irregular boundary.

2Cg 140-165cm. Very pale brown (10YR 7/4) moist, with common coarse prominent strong brown (7.5YR 4/6) mottles; loamy sand; weak fine subangular blocky; friable moist, nonsticky nonplastic wet.

Profile Number: AR6

Soil Name: Talbut series

Higher Category Classification: Kanhaplic Haplustalf

Date of Examination: December 16, 1987

Location: About 1.0km from profile AR5 upslope (i.e 8.0 kilometres from the bridge on Sokoto river.

Landform

(i) Physiography: Upland (middle-slope)

(ii) Topography: Undulating

Slope: 3.5%

Vegetation and Land-use: Grasses, used for sorghum/cowpea cultivation in the rainy season.

Parent Material: Colluvial material

Drainage: Somewhat poorly-drained

Moisture condition in profile: Moist throughout

Depth of groundwater table: Well below 180cm.

A 0-22cm. Dark brown (10YR 3/5) moist; fine sandy loam; moderate medium subangular blocky; friable moist, slightly sticky slightly plastic wet; few fine grass and sorghum roots; clear smooth boundary.

Bt_1 22-41cm. Brown (7.5YR 5/4) moist, with few fine faint strong brown (7.5YR 4/6) mottles; fine sandy loam; moderate medium subangular blocky; thin void cutans; friable moist, sticky and plastic wet; few fine grass and sorghum roots; clear wavy boundary.

Bt_2 41-59cm. Yellowish brown (10YR 5/4) moist, with common fine distinct brown (7.5YR 5/4) mottles; sandy clay loam; weak medium angular blocky; thin void cutans; firm moist, very sticky very plastic wet; many small spherical black Mn/Fe nodules and concretions; clear smooth boundary.

Bt_3 59-88cm. Brown (10YR 5/3) moist, with common medium distinct strong brown (7.5YR 5/6) mottles; sandy clay loam; weak medium subangular blocky to massive; firm moist, sticky and plastic wet; gradual smooth boundary.

BC 88-113cm. Yellowish brown (10YR 6/3) moist, with common medium distinct reddish yellow (7.5YR 6/6) mottles; fine sandy loam; weak fine subangular blocky; friable moist, slightly sticky slightly plastic wet; abrupt wavy boundary.

C 113-180cm+ Yellow (10YR 8/6) moist, with common coarse distinct reddish yellow (7.5YR 6/6) mottles; loamy sand; weak very fine subangular blocky; friable moist, nonsticky nonplastic wet.

Lumda transect

Profile Number: LD1

Soil Name: Giwando series

Higher Category Classification: Typic Pellustert

Date of Examination: November 25, 1987

Author of Description: G.O. Oyediran

Location: About 200 metres off Maiduguri - Dikwa road, 2.7 kilometres southwest of Lumda (approximately 11°58'N, 13°45'E), Bornu State of Nigeria.

Elevation: 320 metres above sea level.

Landform

(i) Physiographic position of the site: Plain

(ii) Topography of surrounding country: Flat

(iii) Microtopography: Nil

Slope on which profile is sited: 1.0

Vegetation or Land-use: Fairly green short grasses; used for grazing.

Climate: Hot subhumid tropical, Mean annual rainfall is about 650mm. The climatic regime consists of a dry season followed by a shorter wet season and then harmattan. Mean mid-day airtemperature is approximately 28°C.

Parent Material: Shale-dominated lacustrine.

Drainage: Somewhat poorly-drained

Moisture condition in profile: Dry from surface to 38cm but moist below.

Depth of groundwater table: Well below 162cm.

Presence of surface stones, rock outcrops: Nil

Evidence of erosion: None, but many coarse cracks (approximately 7cm wide).

Presence of salt or alkali: Nil

Human influence: Nil

A 0-18cm. Dark gray (2.5Y 4/0) dry, very dark gray (2.5Y 3/0) moist; clay; strong medium subangular blocky; very hard dry, very firm moist, very stickly very plastic wet; many coarse cracks (approximately 7cm wide); clear wavy boundary.

AB 18-38cm. Dark gray (2.5Y 4/0) dry, very dark gray (2.5Y 3/0) moist; clay; strong medium angular blocky; very hard dry, very firm moist, very sticky very plastic wet; common medium (about 4cm wide) cracks; gradual wavy boundary.

Bw_1 38-57cm. Dark grayish brown (2.5Y 4/2) moist, with few fine very faint very dark grayish brown (2.5Y 3/2) mottles; clay; moderate medium angular blocky; very firm moist, very sticky very plastic wet; prominent slickensides; diffuse smooth boundary.

Bw_2 57-96cm. Very dark gray (2.5Y 3/0) moist; clay; weak medium angular blocky; very firm moist, very sticky very plastic wet; prominent slickensides; gradual smooth boundary.

2BC 96-119cm. Very dark gray (10YR 3/1) moist, with few fine distinct very pale brown (10YR 7/3) mottles; clay; weak and moderate coarse angular blocky; very firm moist, very sticky very plastic wet; clear smooth boundary.

2C 119-162cm. Brown (10YR 5/3) moist, with common fine distinct dark yellowish brown (10YR 4/6) mottles; sandy loam; weak very fine crumb; friable moist, slightly sticky slightly plastic wet.

Profile Number: LD2

Soil Name: Giwando series

Higher Category Classification: Typic chromustert

Date of Examination: November 25, 1987

Location: About 150 metres from profile LD1

Landform

(i) Physiography: Plain

(ii) Topography: Flat

(iii) Microtopography: Nil

Vegetation and Land-use: Fairly tall (about 1.5 metres) dry grasses and thorny shrubs (e.g Acacia albida); used for grazing.

Parent Material: lacustrine

Drainage: Somewhat poorly-drained

Moisture condition in profile: Dry at the surface but moist below.

Depth of groundwater table: Well below 181cm.

Evidence of Erosion: None, but many fine cracks (about 2 to 3cm wide).

A 0-14cm. Very dark grayish brown (10YR 3/2) dry, very dark gray (10YR 3/1) moist; sandy loam; weak medium subangular blocky; hard dry, firm moist; sticky and plastic wet; many fine cracks (about 2 to 3cm wide); few fine roots; clear smooth boundary.

2BA 14-44cm. Very dark grayish brown (10YR 3/2) moist, with few fine faint yellowish brown (10YR 5/6) mottles; clay loam; strong coarse angular blocky; very firm moist, very sticky very plastic wet; few fine cracks (approximately 2cm. wide); few fine grass roots; diffuse smooth boundary.

$2Bw_1$ 44-85cm. Dark gray (10YR 4/1) moist, with common medium faint yellowish brown (10YR 5/6) mottles; sandy clay loam; moderate and strong medium angular blocky; very firm moist, very sticky very plastic wet; faint slickenside; gradual smooth boundary.

$2Bw_2$ 85-117cm. Very dark gray (10YR 3/1) moist, with common medium faint yellowish brown (10YR 5/6) mottles; sandy clay; moderate medium angular blocky; very firm moist, very sticky very plastic wet; gradual smooth boundary.

2BC 117-137cm. Very dark grayish brown (10YR 3/2) moist, with many fine distinct light live brown (2.5Y 5/4) mottles; sandy clay loam; weak very fine crumb, firm moist, slightly sticky slightly plastic wet; clear smooth boundary.

2C 137-181cm. Very pale brown (10YR 7/4) moist, with many medium prominent yellowish brown (10YR 5/6) and dark yellowish brown (10YR 4/6) mottles; sandy loam; weak very fine crumb; friable moist, nonsticky nonplastic wet.

Profile Number LD3

Soil Name: Barriki series

Higher Category Classification: Quartzipsammentic Haplumbrept

Date of Examination: November 25, 1987

Location: About 180 metres from profile LD2 (on the other side of Maiduguri-Dikwa road).

Landform

(i) Physiography: Fairly plain sand ridge.

(ii) Topography: Flat

(iii) Microtopography: sand ridge

Vegetation and Land-use: Fairly tall (about 1.5 metres) dry grasses and few thorny shrubs (e.g. Acacia albida); used for grazing.

Parent Material: lacustrine

Drainage: Well-drained

Moisture condition in profile: Dry at the surface but moist below.

Depth of groundwater table: Well below 160cm.

A 0-24cm. Grayish brown (10YR 5/2) dry, brown (10YR 5/3) moist; sand; weak very fine crumb; hard dry, friable moist, nonsticky nonplastic wet, common medium pores (channels); few very fine grass roots; clear smooth boundary.

AB 24-44cm. Light gray (10YR 7/2) moist; sand; weak medium subangular blocky; friable moist, nonsticky nonplastic wet; common medium pores (channels); clear smooth boundary.

$2Bw_1$ 44-56cm. Very pale brown (10YR 7/3) moist, with few fine faint yellowish brown (10YR 5/8) mottles; loamy sand; moderate medium subangular blocky; friable moist; slightly sticky slightly plastic wet; gradual wavy boundary.

$2Bw_2$ 56-85cm. Very pale brown (10YR 7/3) moist, with common fine distinct yellowish brown (10YR 5/8) mottles; sandy loam; moderate medium subangular blocky; friable moist, sticky and plastic wet; gradual wavy boundary.

$2Bw_3$ 85-115cm. Light yellowish brown (10YR 6/4) moist, with common medium distinct strong brown (7.5YR 4/6) mottles; sandy clay loam; moderate medium angular blocky; firm moist, very sticky very plastic wet; clear smooth boundary.

3CB 115-160cm. Light yellowish brown (10YR 6/4) moist; sandy clay loam; moderate medium subangular blocky; friable moist, sticky and plastic wet.

Appendix B Bulk density and particle size distribution

Horizon	Depth (cm)	Bulk density g cc^{-1}	Very coarse sand 2 – 1mm	Coarse sand 1 – .45	Medium sand .45 – .225	Fine sand .225–.075	Very fine sand .075–.05	Total sand	Silt .05–.002	Clay <.002mm	Textural class
					%						
					Makurdi transect						
Pedon MDI; Typic Ustifluvent											
Ap_1	0–24	1.88	2.2	2.6	4.0	9.2	11.4	29.4	30.4	40.2	Clay loam
A_2	24–59	1.87	2.4	6.3	9.5	14.2	22.5	54.9	18.6	26.5	Sandy clay loam
$2BA_1$	59–87	1.79	5.3	7.1	16.8	27.7	29.4	86.3	3.9	9.8	Loamy sand
$2BA_2$	87–120	1.82	10.3	3.5	12.3	23.8	30.5	80.4	4.9	14.7	Loamy Sand
2BC	120–168	1.86	5.6	4.1	11.6	16.0	17.6	55.9	19.6	25.5	Sandy clay loam
Pedon MD2; Typic Udifluvent											
A	0–25	1.84	0.4	0.6	1.9	4.0	4.9	11.8	23.5	64.7	Clay
BA	25–60	1.80	0.4	0.5	2.4	3.5	4.0	10.8	29.4	59.8	Clay
Bw_1	60–97	1.89	0.4	1.0	3.9	4.5	5.9	15.7	21.6	62.7	Clay
Bw_2	97–130	1.77	0.2	0.9	4.9	7.5	9.0	22.5	30.4	47.1	Clay
BC	130–171	1.82	0.3	0.6	2.6	3.2	4.1	10.8	36.3	52.9	Clay
Pedon MD3; Andaqueptic Fluvaquent											
A	0–30	2.14	0.6	1.3	2.1	3.0	3.8	10.8	22.5	66.7	Clay
BA	30–45	2.06	0.2	0.9	1.8	2.2	2.7	7.8	25.5	66.7	Clay
2Bw1	45–70	1.92	1.1	1.4	2.9	4.6	6.7	16.7	22.5	60.8	Clay
$2Bw_2$	70–113	1.96	0.5	2.0	4.1	5.9	7.1	19.6	17.7	62.7	Clay
2BCg	113–182	1.94	0.3	2.3	4.8	5.8	6.4	19.6	13.7	66.7	Clay
Pedon MD4; Aquic Kandiustult											
A	0–22	1.69	1.0	1.7	4.9	4.8	5.2	17.6	31.4	51.0	Clay
BA	22–64	1.90	0.6	1.2	2.6	2.1	3.3	9.8	23.5	66.7	Clay
Bwc1	64–90	1.90	0.3	0.5	2.7	2.3	3.0	8.8	22.6	68.6	Clay
Bwc2	90–128	1.84	0.3	0.5	2.5	3.7	4.8	11.8	25.5	62.7	Clay
BCg	128–185	1.81	1.2	1.6	5.7	5.3	5.8	19.6	18.6	61.8	Clay
Pedon MD5; Typic Kandiustalf											
A	0–26	1.78	3.6	5.1	8.1	14.6	15.7	47.1	32.3	20.6	Loam
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.7	11.5	13.6	[illegible]	22.6	37.2	Clay loam

Appendix B Continued.

B_{t1}	59-80	1.86	3.3	4.3	6.9	9.9	12.9	37.3	18.6	44.1	Clay
B_{t2}	80-124	1.85	1.6	5.9	5.1	8.5	8.3	29.4	22.6	48.0	Clay
C	124-185	1.79	2.8	6.0	6.4	6.2	9.6	31.4	19.6	49.0	Clay
				Gadza transect							
Pedon GZ1; Typic Tropaquept											
A	0-21	1.92	4.3	7.5	14.2	18.7	21.0	65.7	22.5	11.8	Sandy loam
BA	21-52	1.95	4.4	6.8	14.5	22.4	26.4	74.5	5.9	19.6	Sandy loam
Bw	52-95	1.94	3.3	5.6	8.9	15.3	19.8	52.9	34.3	12.8	Loam
BC	95-129	1.88	3.9	8.1	13.0	16.9	26.7	68.6	23.5	7.9	Sandy loam
Cg	129-192	1.87	3.9	8.9	16.7	23.5	21.5	74.5	17.7	7.8	Sandy loam
Pedon GZ2; Typic Tropaquept											
Ap	0-11	1.93	5.0	9.2	15.0	19.7	25.6	74.5	15.7	9.8	Sandy loam
AB_1	11-32	1.94	13.8	9.5	17.0	22.6	27.6	90.2	3.9	5.9	Coarse sand
AB_2	32-60	1.91	6.9	10.9	22.8	28.0	25.5	94.1	2.0	3.9	Sand
2BA	60-110	2.02	4.0	14.8	12.3	18.1	21.4	70.6	15.7	13.7	Sandy loam
2Cg	110-168	1.84	15.7	15.0	14.7	22.7	23.1	91.2	2.0	6.8	Coarse sand
Pedon GZ3; Typic Tropaquept											
A	0-18	1.91	6.5	16.5	16.0	23.3	24.0	86.3	5.9	7.8	Loamy coarse sand
AB_1	18-55	1.96	5.3	11.0	18.6	21.7	27.7	84.3	6.9	8.8	Loamy sand
AB_2	55-96	1.90	6.2	11.9	18.6	21.5	18.3	76.5	15.7	7.8	Sandy loam
$2BA_1$	96-111	1.98	10.5	14.3	13.8	20.3	23.5	82.4	4.9	12.7	Loamy coarse sand
$2BA_2$	111-136	1.90	5.2	11.0	18.6	26.5	26.9	88.2	4.9	6.9	Sand
2BC	136-151	1.95	6.1	13.7	16.4	18.0	30.1	84.3	3.9	11.8	Loamy sand
2C	151-192	1.83	7.9	9.9	19.9	25.0	25.5	88.2	2.0	9.8	Loamy sand
Pedon GZ4; Aquic Quartzipsamment											
Ap	0-20	1.87	9.6	17.9	21.0	17.4	20.4	86.3	4.9	8.8	Loamy coarse sand
AB_1	20-40	1.89	6.2	18.4	16.3	23.6	20.8	85.3	5.9	8.8	Loamy coarse sand
AB_2	40-60	1.86	5.7	24.8	16.7	19.2	17.9	84.3	6.9	8.8	Loamy coarse sand

Appendix B Continued.

BA	60-93	1.91	11.8	24.3	14.5	16.9	16.8	84.3	5.9	9.8	Loamy coarse sand
BC_1	93-169	1.93	14.3	26.9	13.3	10.4	15.5	80.4	9.8	9.8	Loamy coarse sand
BCrg2	169-192	1.96	17.9	26.1	14.8	10.2	10.4	79.4	5.9	14.7	Coarse sandy loam
Pedon GZ5; Typic Kandiustult											
A	0-14	1.88	5.6	15.4	13.5	21.3	28.5	84.3	3.9	11.8	Loamy coarse sand
AB	14-37	1.94	11.4	15.6	14.4	17.1	20.9	79.4	4.9	15.7	Coarse sandy loam
BA	37-92	1.95	5.6	9.9	15.2	21.2	26.5	78.4	2.9	18.7	Very fine sandy loam
$2B_{t1}$	92-140	1.97	4.2	7.9	9.1	13.9	16.9	52.0	2.0	46.0	Sandy clay
$2B_{t2}$	140-182	1.99	5.4	6.5	7.9	13.1	14.2	47.1	3.9	49.0	Sandy clay
2C	182-207	1.94	4.7	6.3	8.1	10.5	17.5	47.1	4.9	48.0	Sandy clay
Pedon GZ6; Typic Kandiustult								Sb	Sit	Clay	
A	0-24	1.99	6.2	10.2	15.6	19.5	27.9	79.4	10.8	9.8	Loamy sand
AB	24-59	1.90	5.5	12.0	15.2	22.9	28.7	84.3	4.9	10.8	Very fine sandy loam
$2B_{t1}$	59-97	1.91	5.0	5.9	11.0	15.7	17.3	54.9	3.9	41.2	Sandy clay
$2Bct_2$	97-160	1.96	3.5	9.3	8.4	11.1	16.7	49.0	3.9	47.1	Sandy clay
2C	160-200	1.94	6.3	10.4	10.6	15.0	16.5	58.8	5.9	35.3	Sandy clay

Dwam transect

Pedon DMI; Tropaquent											
A	0-25	1.86	0.8	2.6	4.3	1.3	1.8	10.8	40.2	49.0	Silty clay
BAc	25-44	1.88	0.6	1.9	3.4	2.4	3.5	11.6	44.1	44.1	Silty clay
Bwc_1	44-72	1.90	0.6	1.2	2.1	2.5	3.5	9.9	44.1	46.0	Silty clay
$2Bwc_2$	72-103	1.98	0.6	2.4	6.2	7.1	9.2	25.5	25.5	49.0	Loam
$2Bwc_3$	103-135	1.87	4.0	7.8	17.0	12.6	17.4	58.8	10.8	30.4	Sandy clay loam
2C	135-179	1.79	8.4	23.6	10.6	22.6	21.1	86.3	2.9	10.8	Loamy coarse sand
Pedon DM2; Udic Chromustert											
A	0-20	1.95	0.6	3.2	9.1	5.7	4.9	23.5	14.7	61.8	Clay
AB	10-42	1.97	4.4	6.9	7.7	3.9	1.6	24.5	12.8	62.7	Clay
Bw1	42-74	1.98	3.9	7.8	7.2	3.4	2.2	24.5	13.7	61.8	Clay
Bw2	74-109	2.01	3.2	6.0	7.2	2.8	2.3	23.5	14.7	61.8	Clay
BC	109-165	2.10	3.1	4.3	5.4	1.9	[illegible]	[illegible]	[illegible]	[illegible]	

Appendix B Continued.

Pedon DM3; Typic Kandiustalf											
A	0-18	1.78	11.1	8.3	19.6	8.3	3.7	51.0	24.5	24.5	Sandy clay loam
AB	18-43	1.81	12.7	9.6	15.6	6.5	6.6	51.0	21.6	27.4	Sandy clay loam
B_{t1}	43-76	1.94	14.9	7.3	12.1	5.0	7.8	47.1	20.6	32.3	Sandy clay loam
$2B_{t2}$	76-120	2.00	11.5	3.9	9.3	2.4	2.3	29.4	23.5	47.1	Clay
2C	120-160	1.86	22.7	10.8	17.8	4.4	5.1	60.8	16.7	22.5	Sandy clay loam
R	160-175+	1.84	23.8	16.0	12.0	6.7	5.2	63.7	14.7	21.6	Sandy clay loam
					Argungu transect						
Pedon AR 1: Andaqueptic Fluvaquent											
..	0-25	1.9[illegible]	4.2	4.5	6.1	8.0	10.5	33.3	17.7	49.0	Clay
AB_1	25-61	1.98	4.6	4.3	5.6	10.2	18.4	43.1	19.6	37.3	Clay loam
$2AB_2$	61-101	1.83	6.1	3.9	8.2	22.9	31.4	72.5	11.8	15.7	Very fine sandy loam
2Bwcg1	101-128	1.78	15.7	11.4	9.5	14.9	30.8	82.3	11.8	5.9	Loamy coarse sand
2Bwcg2	128-157	1.86	13.0	10.7	9.7	17.5	23.6	74.5	7.8	17.7	Coarse sandy loam
2BCg1	157-173	1.74	13.6	12.3	11.0	16.6	24.9	78.4	5.9	15.7	Coarse sandy loam
2BCg2	173+	1.71	20.2	14.5	12.6	21.4	19.5	88.2	2.0	9.8	Loamy coarse sand
Pedon AR2; Andaqueptic Fluvaquent											
A	0-24	2.02	5.8	6.0	9.5	15.2	6.6	43.1	3.9	53.0	Clay
Bw1	24-50	1.98	2.4	2.5	6.1	16.7	9.6	37.3	9.8	52.9	Clay
$2Bw_2$	50-77	1.93	7.9	9.1	14.4	23.5	17.7	72.6	3.9	23.5	Sandy clay loam
$2BC_1$	77-110	1.85	9.5	11.7	16.3	29.7	19.1	86.3	2.0	11.7	Loamy sand
$2BC_2$	110-179	1.80	8.3	14.3	15.5	32.1	23.9	94.1	2.0	3.9	Sand
Pedon AR3; Tropaquert											
A	0-31	1.96	0.3	1.0	4.9	11.4	5.9	23.5	19.6	56.9	Clay
BA	31-58	1.99	0.3	0.8	5.2	10.8	6.4	23.5	19.6	56.9	Clay
Bw_1	58-85	1.98	1.0	3.5	6.4	8.8	7.7	27.4	21.6	51.0	Clay
2Bwcg2	85-118	1.76	6.8	10.2	15.3	26.0	16.2	74.5	2.0	23.5	Sandy clay loam
3Bwcg3	118-160	1.87	3.7	3.1	7.3	14.5	10.6	39.2	33.3	27.5	Loam
3B[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							

Appendix B Continued.

Pedon AR4; Typic Ustropept											
A	0-18	1.89	6.7	8.3	11.0	30.4	20.1	76.5	5.9	17.6	Fine sandy loam
Bw	18-50	1.91	4.2	9.5	11.2	27.3	15.5	67.7	5.9	26.4	Sandy clay loam
BC	50-85	1.82	9.9	13.8	15.7	29.4	19.4	88.2	2.0	9.8	Loamy coarse sand
C	85-170	1.68	14.1	16.7	17.9	26.8	19.6	95.1	2.0	2.9	Coarse sand
Pedon AR5; Albaquic Paleudalf											
A	0-21	1.88	5.3	6.8	10.2	27.9	20.4	70.6	7.8	21.6	Sandy clay loam
BA	21-40	1.96	1.6	4.3	6.9	24.0	8.5	45.3	15.7	39.0	Sandy clay
B_{t1}	40-71	1.98	2.2	3.8	5.5	11.9	7.0	30.4	17.6	52.0	Clay
B_{t2}	71-110	1.99	1.4	3.6	6.1	10.1	9.2	30.4	17.6	52.0	Clay
BCg	110-140	2.00	2.6	4.8	6.3	13.4	9.1	41.2	23.3	25.5	Loam
2Cg	140-165	1.84	8.8	12.4	13.7	31.8	16.6	85.3	2.9	11.8	Loamy sand
Pedon AR6; Kanhaplic Haplustalf											
A	0-22	1.86	4.9	6.4	9.1	30.3	17.9	68.6	14.7	16.7	Fine sandy loam
B_{t1}	22-41	1.89	5.3	7.7	8.6	39.4	7.6	68.6	11.8	19.6	Fine sandy loam
B_{t2}	41-59	1.92	3.1	4.3	7.2	32.2	17.9	64.7	8.8	26.5	Sandy clay loam
B_{t3}	59-86	1.95	2.2	4.6	7.0	25.8	21.2	60.8	11.8	27.4	Sandy clay loam
BC	86-113	1.84	4.5	5.2	9.3	38.7	18.8	76.5	5.9	17.6	Fine sandy loam
C	113-180+	1.72	6.8	9.4	12.5	40.6	14.0	83.3	3.0	13.7	Loamy sand

Lumda transect

Pedon LD1; Typic Pellustert											
A	0-18	2.06	0.1	0.2	10.7	8.0	8.4	27.4	11.8	60.8	Clay
AB	18-38	2.08	0.1	0.2	8.6	6.8	7.8	23.5	12.8	63.7	Clay
Bw1	38-57	2.10	0.1	0.2	7.1	6.8	7.4	21.6	11.7	66.7	Clay
Bw2	57-96	2.13	0.1	0.2	6.8	6.0	4.5	17.6	15.7	66.7	Clay
2BC	96-119	1.97	0.2	0.4	20.0	15.2	7.3	43.1	6.9	50.0	Clay
2C	119-162	1.82	1.2	0.9	39.7	23.8	13.8	79.4	2.9	17.7	Sandy loam

Appendix B Continued

Pedon LD2; Typic Chromustert											
A	0-14	1.75	0.8	4.9	26.6	22.4	23.7	78.4	3.9	17.7	Sandy loam
2BA	14-44	1.99	0.4	2.1	17.2	12.9	11.3	43.9	16.9	39.2	Clay loam
2Bw1	44-85	1.92	0.7	0.1	22.4	16.6	21.0	60.8	5.9	33.3	Sandy clay loam
2Bw2	85-117	1.93	0.3	1.0	19.6	17.6	20.3	58.8	3.9	37.3	Sandy clay
2BC	117-137	1.79	0.4	1.3	22.2	19.8	26.9	70.6	2.0	27.4	Sandy clay loam
2C	137-181	1.77	0.4	1.2	33.6	19.5	24.7	79.4	2.0	18.6	Sandy loam
Pedon LD3; Oxic Ustropept											
A	0-24	1.79	0.6	2.1	35.3	29.6	22.6	90.2	2.0	7.8	Sand
AB	24-44	1.74	0.3	1.4	34.1	36.7	20.6	93.1	1.0	5.9	Sand
2Bw1	44-56	1.87	0.7	5.7	29.2	25.0	22.7	83.3	3.0	13.7	Loamy sand
2Bw2	56-85	1.89	0.5	1.6	34.0	27.1	19.1	82.3	1.0	16.7	Sandy loam
2Bw3	85-115	1.96	0.3	0.9	31.6	21.6	18.1	72.5	5.9	21.6	Sandy clay loam
3CB	115-160	1.91	0.1	12.3	33.8	14.5	7.9	68.6	3.9	27.5	Sandy clay loam

Appendix C: Particle size distribution (clay-free basis) of the soils.

Horizon	Depth(cm)	Very coarse sand 2.0 - 1.0	Coarse sand 1.0 - .45	Medium sand .45 - .225	Fine sand .225 - .075	Very fine .075 - .05	Total sand	Silt .05 .002
		%						
Makurdi transect								
Pedon MD1; Typic Ustifluvent								
A_{P1}	0-24	3.7	4.3	6.7	15.4	19.1	49.2	50.8
A_2	24-59	3.3	8.6	12.9	19.3	30.6	74.7	25.3
$2BA_1$	59-87	5.9	7.9	18.6	30.7	32.6	95.7	4.3
$2BA_2$	87-120	12.1	4.1	14.4	27.9	35.8	94.3	5.7
2BC	120-168	7.5	5.5	15.6	21.5	23.6	73.7	26.3
Pedon MD2; Typic Udifluvent								
A	0-25	1.1	1.7	5.4	11.3	13.9	33.4	66.6
BA	25-60	1.0	1.2	6.0	8.7	10.0	26.9	73.1
Bw_1	60-97	1.1	2.7	10.4	12.1	15.8	42.1	57.9
Bw_2	97-130	0.4	1.7	9.3	14.2	16.9	42.5	57.5
BC	130-171	0.6	1.3	5.5	6.8	8.7	22.9	77.1
Pedon MD3; Andaqueptic Fluvaquent								
A	0-30	1.8	3.9	6.3	9.0	11.4	32.4	67.6
BA	30-45	0.6	2.7	5.4	6.6	8.1	23.4	76.6
$2Bw_1$	45-70	2.8	3.6	7.4	11.7	17.1	42.6	57.4
$2Bw_2$	70-113	1.3	5.4	11.0	15.8	19.0	52.5	47.5
$2BC_g$	113-182	0.9	6.9	14.4	17.4	19.3	58.9	41.1

Appendix C (contd.)

Pedon MD4; Aquic Kandiustult

A	0-22	2.0	3.5	10.0	9.8	10.6	35.9	64.1
BA	22-64	1.8	3.6	7.8	6.3	9.9	29.4	70.6
Bwc_1	64 90	1.0	1.6	8.6	7.3	9.5	28.0	72.0
Bwc_2	90-128	0.8	1.3	6.7	9.9	12.9	31.6	68.4
BC_g	128-185	3.1	4.2	14.9	3.9	15.2	51.3	48.7

Pedon MD5; Typic Kandiustalf

A	0-26	4.5	6.4	10.2	18.4	19.8	59.3	40.7
BA	26-59	3.9	7.8	12.3	18.3	21.7	64.0	36.0
B_{t1}	59-80	5.9	7.7	12.3	17.7	23.1	66.7	33.3
B_{t2}	80-124	3.1	11.3	9.8	16.3	16.0	56.5	43.5
C	124-185	5.5	11.8	12.5	12.2	19.6	61.6	38.4

<u>Gadza transect</u>

Pedon GZ1; Typic Tropaquept

A	0-21	4.9	8.5	16.1	21.2	23.9	74.5	25.5
BA	21-52	9.5	8.5	18.0	27.9	28.8	92.7	7.3
Bw	52-95	3.8	6.4	10.2	17.5	22.8	60.7	39.3
BC	95-129	4.2	8.8	14.1	18.3	23.1	74.5	25.5
Cg	129-192	4.2	9.6	18.1	25.5	23.4	80.8	19.2

Pedon GZ2; Typic Tropaquept

Ap	0-11	5.5	10.2	16.6	21.8	29.5	83.6	16.
AB_1	11-32	14.7	10.1	18.1	24.0	29.0	95.9	4.
AB_2	32-60	7.2	11.3	23.7	29.1	26.6	97.9	2.
2BA	60-110	4.6	17.2	14.3	21.0	24.9	82.0	18.
2Cg	110-168	16.8	16.1	15.8	24.4	24.7	97.8	2.

Pedon GZ3; Typic Tropaquept

A	0-18	7.1	17.9	17.4	25.3	25.9	93.6	6.
AB_1	18-55	5.8	12.1	20.4	23.8	30.3	92.4	7.
AB_2	55-96	6.7	12.9	20.0	23.3	19.9	83.0	17.
$2BA_1$	96-111	12.0	16.4	15.8	23.3	26.9	94.4	5.
$2BA_2$	111-136	5.6	11.8	20.0	28.5	28.8	94.7	5.
2BC	136-151	6.9	15.5	18.6	20.4	34.2	95.6	4.
2C	151-192	8.8	11.0	22.1	27.7	28.2	97.8	2.

Pedon GZ4; Aquic Quartzipsamment

Ap	0-20	10.5	19.6	23.0	19.1	22.4	94.6	5.
AB_1	20-40	6.8	20.2	17.9	25.9	22.7	93.5	6.
AB_2	40-60	6.3	27.2	18.3	21.1	19.5	92.4	7.
BA	60-93	13.1	26.9	16.1	18.7	18.7	93.5	6.
BC_1	93-169	15.8	29.8	14.7	11.5	17.2	89.1	10.
BGg2	169-192	21.0	30.6	17.3	12.0	12.2	93.1	6.

Appendix C (contd.)

Pedon GZ5; Typic Kandiustult.

A	0-14	6.3	17.5	15.3	24.1	32.4	95.6	4.4
AB	14-37	13.5	18.5	17.1	20.3	24.8	94.2	5.8
BA	37-92	6.9	12.2	18.7	26.1	32.5	96.4	3.6
$2B_{t1}$	92-140	7.8	14.6	16.8	25.8	31.3	96.3	3.7
$2B_{t2}$	140-182	10.6	12.7	15.5	25.7	27.9	92.4	7.6
2C	182-207	9.0	12.1	15.6	20.2	35.4	92.3	7.7

Pedon GZ6; Typic Kandiustult

A	0-24	6.9	11.3	17.3	21.6	30.9	88.0	12.0
AB	24-59	6.2	13.5	17.0	25.7	32.1	94.5	5.5
$2B_{t1}$	59-97	8.5	10.0	18.7	26.7	29.5	93.4	6.6
$2Bct_2$	97-160	6.6	17.6	15.9	21.0	31.5	92.6	7.4
2C	160-200	9.7	16.1	16.4	23.2	25.5	90.9	9.1

Dwam transect

Pedon DM1; Tropaquent

A	0-25	1.6	5.1	8.4	2.5	3.6	21.2	78.8
BA_c	25-44	1.1	3.4	6.1	4.3	6.2	21.1	78.9
Bwc_1	44-72	1.1	2.2	3.9	4.6	6.5	18.3	81.7
$2Bwc_2$	72-103	1.2	4.7	12.2	13.9	18.0	50.0	50.0
$2Bwc_3$	103-135	5.7	11.2	24.4	18.1	25.1	84.5	15.5
2C	135-179	9.4	26.5	11.9	25.3	23.6	96.7	3.3

Pedon DM2; Udic Chromustert

A	0-20	1.6	8.4	23.8	14.9	12.8	61.5	38.5
AB	20-42	11.8	18.5	20.6	10.5	4.3	65.7	34.3
Bw_1	42-74	10.2	20.4	18.8	8.9	5.8	64.1	35.9
Bw_2	74-109	8.4	20.9	18.8	7.3	6.1	61.5	38.5
BC	109-165	9.0	12.5	15.7	5.5	3.1	45.8	54.2

Pedon DM3; Typic Kandiustalf

A	0-18	14.7	11.0	26.0	11.0	4.8	67.5	32.5
AB	18-43	17.5	13.2	21.5	8.9	9.1	70.2	29.8
B_{t1}	43-76	22.0	10.8	17.9	7.4	11.3	69.4	30.6
$2B_{t2}$	76-120	21.7	7.4	17.6	4.5	4.4	55.6	44.4
2C	120-160	29.3	13.9	23.0	5.7	6.6	78.5	21.5
R	160-175+	30.4	20.4	15.3	8.5	6.7	81.3	18.7

Argungu transect

Pedon AR1; Andaqueptic Fluvaquent

A	0-35	8.2	8.8	12.0	15.7	20.6	65.3	34.7
AB_1	35-61	7.3	6.9	8.9	16.3	29.3	68.7	31.3
$2AB_2$	61-101	7.2	4.6	9.7	27.2	37.3	86.0	14.0
$2Bwcg_1$	101-128	16.7	12.1	10.1	15.8	32.8	87.5	12.5
$2Bwcg_2$	128-157	15.8	13.0	11.8	21.3	28.6	90.5	9.5
$2BCg_1$	157-173	16.1	14.6	13.0	19.7	29.6	93.0	7.0
$2BCg_2$	173+	22.4	16.1	14.0	23.7	21.6	97.8	2.2

Appendix C (contd.)

Pedon AR2; Andaqueptic Fluvaquent

A	0-24	12.3	12.8	20.2	32.3	14.1	91.7	8.2
Bw_1	24-50	5.1	5.3	12.9	35.5	20.4	79.2	20.8
$2Bw_2$	50-77	10.3	11.9	18.8	30.7	23.2	94.9	5.1
$2BC_1$	77-110	10.8	13.3	18.5	33.6	21.5	97.7	2.3
$2BC_2$	110-179	8.6	14.9	16.1	33.4	24.9	97.9	2.1

Pedon AR3; Tropaquent

A	0-31	0.7	2.3	11.4	26.5	13.6	54.5	45.5
BA	31-58	0.7	1.9	12.1	25.1	14.7	54.5	45.5
Bw_1	58-85	2.0	7.1	13.1	18.0	15.2	55.9	44.1
$2Bwcg_2$	85-118	8.9	13.3	20.0	34.0	21.2	97.4	2.6
$3Bwcg_3$	118-160	5.1	4.3	10.1	20.0	14.6	54.1	45.9
3BCg	160-194	12.5	18.3	14.6	24.6	16.9	86.9	13.1

Pedon AR4; Typic Ustropept

A	0-18	8.1	10.1	13.3	36.9	24.4	92.8	7.2
Bw	18-50	5.7	12.9	15.2	37.1	21.1	92.0	8.0
BC	50-85	11.0	15.3	17.4	32.6	21.5	97.8	2.2
C	85-170	14.5	17.2	18.4	27.6	20.3	98.0	2.0

Appendix C (contd.)

Pedon AR5; Albaquic Paleudalf

A	0-21	6.8	8.7	13.0	35.6	25.9	90.0	10.0
BA	21-40	2.6	7.0	11.3	39.3	14.1	74.3	25.7
B_{t1}	40-71	4.6	7.9	11.5	24.8	14.5	63.3	33.7
B_{t2}	71-110	2.9	7.5	12.7	21.0	19.2	63.3	33.7
BCg	110-140	3.5	6.4	8.5	24.7	12.2	55.3	44.7
2Cg	140-165	10.0	14.1	15.5	36.0	21.1	96.7	3.3

Pedon AR6; Kanhaplic Haplustalf

A	0-22	5.9	7.7	10.9	36.4	21.4	82.3	17.7
B_{t1}	22-41	6.6	9.6	10.7	49.0	9.4	85.3	14.7
B_{t2}	41-59	4.2	5.8	9.8	43.8	24.4	88.0	12.0
B_{t3}	59-88	3.0	6.3	9.6	35.5	29.3	83.7	16.3
BC	88-113	5.5	6.3	11.3	47.0	22.7	92.8	7.2
C	113-180+	7.9	10.9	14.5	47.0	16.2	96.5	3.5

Lumda transect

Pedon LD1; Typic Pellustert

A	0-18	0.3	0.5	27.3	20.4	21.4	69.9	30.1
AB	18-38	0.3	0.6	23.7	18.7	21.4	64.7	35.3
Bw_1	38-57	0.3	0.6	21.3	20.4	22.3	64.9	35.1
Bw_2	57-96	0.3	0.6	20.4	18.0	13.5	52.8	47.2
2BC	96-119	0.4	0.8	40.0	30.4	14.6	86.2	13.8
2C	119-162	1.5	1.1	48.2	28.9	16.8	96.5	3.5

Appendix C (contd.)

Pedon LD2; Typic Chromustert								
A	0-14	1.0	5.9	32.3	27.2	28.9	95.3	4.7
2BA	14-44	0.7	3.5	28.3	21.2	18.5	72.2	27.8
$2Bw_1$	44-85	1.0	0.2	33.6	24.9	31.4	91.1	8.9
$2Bw_2$	85-117	0.5	1.6	31.3	28.1	32.3	93.8	6.2
2BC	117-137	0.6	1.8	30.6	27.3	36.9	97.2	2.8
2C	137-181	0.5	3.5	41.3	24.0	28.2	97.5	2.5
Pedon LD3; Oxic Ustropept								
A	0-24	0.7	2.3	38.3	32.1	24.4	97.8	2.2
AB	24-44	0.3	1.5	36.2	39.0	21.9	98.9	1.1
$2Bw_1$	44-56	0.8	6.6	33.8	29.0	26.3	96.5	3.5
$2Bw_2$	56-85	0.6	5.9	40.8	28.5	23.0	98.8	1.2
$2Bw_3$	85-115	0.4	1.1	40.3	27.6	23.1	92.5	7.5
3CB	115-160	0.1	17.0	46.6	20.0	10.9	94.6	5.4

Appendix D: Soil pH, cation exchange capacity, base saturation and electrical conductivity date.

Horizon	Depth (cm)	pH(H_2O)	pH(1.0M KCl)	Ca^{2+}	Mg^{2+}	Na^+	K^+	Exchange acidity (+)	ECEC	CEC (pH8.2)	PDC(ΔCEC)	Base saturation Effective	Base saturation ΣCations	Na saturation	EC
				cmol kg⁻¹ soil								%			dSm⁻¹
				Makurdi transect											
Pedon MD1; Typic Ustifluvent															
Ap1	0-24	6.5	6.3	1.62	1.30	0.13	0.18	0.50	3.73	9.83	6.10	86.6	32.8	4.02	0.4
A2	24-59	6.4	6.2	2.14	1.00	0.10	0.17	0.69	4.10	13.53	9.43	83.2	25.2	2.93	0.3
$2BA_1$	59-87	6.5	6.2	0.91	0.45	0.07	0.09	0.51	2.03	5.67	3.64	74.9	26.8	4.60	0.1
$2BA_2$	87-120	6.5	6.2	1.59	0.57	0.10	0.13	0.44	2.83	7.61	4.78	84.4	31.4	4.18	0.3
2BC	120-168	6.4	6.2	1.62	1.03	0.09	0.17	0.48	3.39	8.35	4.96	85.8	34.8	3.09	0.2
Pedon MD2; Typic Udifluvent															
A	0-25	4.2	4.0	1.86	0.56	0.61	0.25	0.87	4.15	9.87	5.72	79.0	33.2	18.59	0.2
BA	25-60	6.3	6.1	1.09	0.19	0.15	0.21	0.56	2.20	7.04	4.84	74.5	23.3	9.15	0.3
Bw1	60-97	6.2	6.1	1.21	0.34	0.18	0.28	0.24	2.25	7.83	5.58	89.3	25.7	8.95	0.2
Bw2	97-130	6.2	6.1	1.83	0.60	0.13	0.42	0.31	3.29	11.51	8.22	90.6	25.9	4.36	0.2
BC	130-171	6.4	6.2	2.06	0.85	0.14	0.76	0.28	4.09	11.67	7.58	93.1	32.6	3.67	0.1
Pedon MD3; Andaqueptic Fluvaquent															
A	0-30	4.9	4.7	4.01	1.69	0.26	0.44	0.29	6.69	25.44	18.75	95.7	25.1	4.06	0.1
BA	30-45	5.2	5.0	2.97	1.24	0.18	0.30	0.19	4.88	16.02	11.14	96.1	29.3	3.84	0.2
2Bw1	45-70	5.9	5.8	3.10	1.35	0.19	0.42	0.49	5.55	12.98	7.43	91.2	39.0	3.75	0.2
2Bw2	70-113	6.1	5.9	4.96	2.14	0.22	0.76	0.65	8.73	25.51	16.78	92.6	31.7	2.72	0.2
2BCg	113-182	5.8	5.7	4.42	2.25	0.09	0.23	0.45	7.44	24.72	17.28	93.9	28.3	1.29	0.3
Pedon MD4; Aquic Kandiustult															
A	0-22	5.3	5.2	2.33	1.04	0.30	0.31	0.33	4.31	14.24	9.93	92.3	27.9	7.54	0.1
BA	22-64	5.6	5.5	2.23	0.93	0.18	0.30	0.29	3.93	10.60	6.67	96.2	34.3	4.94	0.2
Bwc1	64-90	6.2	6.0	2.49	1.18	0.22	0.40	0.34	4.63	14.55	9.92	92.7	29.5	5.13	0.2
Bwc2	90-128	6.2	6.0	1.99	0.97	0.13	0.28	0.41	3.78	9.80	6.02	89.1	34.4	3.86	0.2
BCg	128-165	6.3	6.2	2.46	1.41	0.15	0.36	0.20	4.58	14.11	9.53	95.6	31.0	3.42	0.2
Pedon MD5; Typic Kandiustalf															
A	0-26	6.4	6.2	2.35	1.52	.13	0.77	0.66	5.43	12.35	6.92	87.8	38.6	2.72	0.3
BA	26-59	6.3	6.2	1.48	0.79	0.08	0.19	0.41	2.95	6.63	3.68	86.1	38.3	3.15	0.2
B_{t1}	59-80	6.2	6.1	1.81	1.03	0.10	0.18	0.23	3.35	8.46	5.11	93.1	36.9	3.20	0.3

Appendix D Continued.

		pH H_2O	pH KCl	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Acidity	eCEC	CEC pH 8	ΔCEC	Base Satn eCEC	Base satn. (CEC/8.2)	Na satn.	EC dS/m
B_{t2}	80-124	6.2	6.1	2.18	0.97	0.09	0.19	0.35	3.78	9.04	5.26	90.7	37.9	2.62	0.5
C	124-185	6.3	6.1	2.20	1.29	0.10	0.22	0.18	3.99	11.89	7.90	95.5	32.0	2.62	0.3
Gadza transect															
Pedon GZ1; Typic Tropaquept															
A	0-21	4.2	3.9	1.52	0.59	0.11	0.20	0.78	3.20	8.47	5.27	75.6	28.6	4.54	0.2
BA	21-52	4.8	4.3	0.84	0.50	0.04	0.11	0.77	2.26	5.22	2.96	65.9	28.5	2.68	0.2
Bw	52-95	5.2	4.7	1.25	0.57	0.04	0.14	0.75	2.75	5.43	2.68	72.7	36.8	2.00	0.3
BC	95-129	5.9	5.4	0.92	0.57	0.05	0.16	1.05	2.75	5.30	2.55	61.8	32.1	2.94	0.2
Cg	129-192	5.9	5.5	0.87	0.57	0.03	0.14	0.35	1.96	3.16	1.20	82.1	50.9	1.86	0.3
Pedon GZ2; Typic Tropaquept															
AB	0-11	4.4	4.0	0.89	0.65	0.07	0.16	0.61	2.38	6.03	3.65	74.4	29.3	3.95	0.1
AB_1	11-32	5.2	4.7	0.81	0.70	0.03	0.13	0.78	2.45	6.92	4.47	68.2	24.1	1.80	0.2
AB_2	32-60	5.3	4.6	0.76	0.60	0.05	0.13	1.33	2.85	8.57	5.72	53.3	17.7	1.97	0.3
2Bw	60-110	5.0	4.6	1.13	0.81	0.11	0.20	0.79	3.04	11.00	7.96	74.0	20.4	4.89	0.2
2Cg	110-168	5.1	4.6	0.86	0.54	0.05	0.12	1.14	2.71	9.45	6.74	57.9	16.6	3.18	0.2
Pedon GZ3; Typic Tropaquept															
A	0-18	4.2	3.9	1.27	0.55	0.04	0.14	0.93	2.93	8.63	5.70	68.3	23.2	2.00	0.1
AB_1	18-55	5.1	4.7	1.04	0.65	0.03	0.12	0.73	2.57	5.28	2.71	71.6	34.8	1.63	0.1
AB_2	55-96	5.3	4.8	0.94	0.63	0.04	0.12	0.89	2.62	6.02	3.40	66.0	28.7	2.31	0.3
$2BA_1$	96-111	5.0	4.5	1.22	0.73	0.12	0.16	0.81	3.04	10.54	7.46	73.4	21.1	5.38	0.3
$2BA_2$	111-136	5.2	4.7	0.82	0.58	0.08	0.13	0.82	2.12	3.88	1.45	66.3	41.5	4.97	0.2
2BC	136-151	4.9	4.5	1.09	0.76	0.14	0.16	0.61	2.76	6.04	3.28	77.9	35.6	6.51	0.1
2C	151-192	4.9	4.5	0.86	0.51	0.10	0.15	0.30	1.92	3.46	2.26	84.4	46.8	6.17	0.1
Pedon GZ4; Aquic Quartzipsamment fringe															
Ap	0-20	5.3	4.8	1.09	0.60	0.06	0.13	0.26	2.14	9.65	7.55	87.9	19.5	3.19	0.2
AB_1	20-40	5.3	4.8	0.70	0.49	0.05	0.12	0.69	2.05	8.39	6.34	66.3	16.2	3.68	0.3
AB_2	40-60	5.2	4.8	0.59	0.44	0.06	0.16	0.36	1.61	4.57	2.96	77.6	27.3	4.80	0.2
BA	60-93	5.0	4.8	0.35	0.21	0.06	0.13	0.34	1.09	4.12	3.03	68.8	18.2	8.00	0.2
BC_1	93-169	5.3	4.9	0.38	0.19	0.05	0.13	0.96	1.71	4.89	3.18	43.9	15.3	6.67	0.2
BC_{rg2}	169-192	5.4	4.9	0.73	0.44	0.06	0.15	0.48	1.86	5.27	3.41	74.2	26.2	4.35	0.2

Appendix D Continued

Pedon GZ5;	Typic Kandiustult Mobile														
A	0-14	5.7	5.2	0.86	0.40	0.06	0.13	0.59	2.04	7.36	5.32	71.1	19.7	4.14	0.4
AB	14-37	5.1	4.6	0.48	0.48	0.05	0.15	0.88	2.04	7.70	5.66	56.9	15.1	4.31	0.2
BA	37-92	4.8	4.6	0.52	0.35	0.04	0.15	1.00	2.06	7.73	5.67	51.5	13.7	3.77	0.1
$2B_{t1}$	92-140	5.0	4.8	1.39	0.81	0.06	0.17	0.95	3.38	8.34	4.96	71.9	29.1	2.47	0.2
$2B_{t2}$	140-182	5.0	4.9	2.40	1.17	0.05	0.18	1.00	4.80	6.91	4.11	79.2	42.6	1.32	0.1
2C	182-207	5.1	5.0	1.45	0.89	0.06	0.19	0.80	3.39	7.89	4.50	76.4	32.8	2.32	0.1
Pedon GZ6;	Typic Kandiustult upland	pH		Ca	Mg	Na	K	Exch	ECEC						
A	0-24	5.5	5.4	0.91	0.50	0.06	0.15	0.74	2.36	6.54	4.18	66.6	24.8	3.70	0.2
AB	24-59	4.9	4.8	0.70	0.56	0.07	0.17	0.38	1.88	5.03	3.15	79.8	29.8	4.67	0.1
$2B_{t1}$	59-97	4.9	4.9	1.00	0.63	0.06	0.17	0.51	2.37	8.25	5.88	78.5	22.5	3.23	0.2
$2B_{ct2}$	97-160	5.0	5.0	0.57	0.16	0.05	0.17	0.39	1.34	2.89	1.55	70.9	32.9	5.26	0.1
2C	160-200	5.0	5.0	0.50	0.24	0.06	0.17	0.64	1.61	3.30	1.69	60.2	29.4	6.18	0.1

Dwam transect

Pedon DM1;	Tropaquent														
A	0-25	6.2	6.0	20.78	7.58	0.60	0.40	0.47	29.83	62.84	33.01	98.4	46.7	2.04	0.3
BAC	25-44	6.1	6.0	12.16	5.63	0.55	0.30	0.30	19.02	46.02	27.00	98.0	40.5	2.95	0.2
Bwc1	44-72	6.2	6.1	15.00	7.03	0.53	0.32	0.31	23.19	53.72	30.53	98.7	42.6	2.32	0.2
2Bwc2	72-103	6.4	6.2	14.76	7.39	0.60	0.35	0.67	23.77	50.64	26.87	97.2	45.6	2.60	0.1
2Bwc3	103-135	6.7	6.4	12.00	6.12	0.55	0.29	0.30	19.26	45.98	26.72	98.4	41.2	2.90	0.5
2C	135-179	6.9	6.6	2.89	1.49	0.25	0.09	0.36	5.08	16.14	11.06	92.9	29.2	5.30	0.6
Pedon DM2:	Udic Chromustert														
A	0-20	6.0	5.9	15.14	7.84	1.01	0.39	0.40	24.78	55.67	30.89	98.4	43.8	4.14	0.2
AB	20-42	6.8	6.5	17.05	6.17	1.69	0.35	0.79	28.05	58.20	30.15	97.2	46.8	6.20	0.5
Bw_1	42-74	6.8	6.7	16.13	8.20	2.51	0.37	0.67	27.88	57.67	29.79	97.6	47.2	9.22	0.3
B_{w2}	74-109	7.1	6.8	16.87	7.07	4.02	0.47	0.25	30.68	64.33	33.65	99.2	47.3	13.21	0.7
BC	109-165	7.8	7.4	19.47	6.75	4.65	0.42	0.17	31.46	68.81	37.35	99.5	45.5	14.86	1.1
Pedon DM3;	Typic Kandiustalf														
A	0-18	7.3	6.2	4.27	0.83	0.17	0.25	0.51	6.03	23.24	17.17	91.5	23.7	3.08	1.0
AB	18-43	6.6	6.0	2.64	0.93	0.19	0.13	0.17	4.10	14.30	10.20	96.1	27.5	4.82	0.6

Appendix D contd.

B_{t1}	43-76	5.5	5.2	1.99	1.24	0.21	0.13	0.29	3.06	9.55	5.69	92.5	37.4	5.88	0.3
$2B_{t2}$	76-120	5.1	4.9	3.47	2.08	0.36	0.15	0.45	6.51	19.07	12.56	93.1	31.8	5.94	0.3
2C	120-160	6.8	6.0	5.34	2.04	0.34	0.27	0.25	8.24	26.67	16.43	97.0	29.9	4.25	0.2
R	160-175+	8.2	7.9	7.06	2.90	0.43	0.30	0.18	10.87	39.48	28.61	98.3	27.1	4.02	0.2
						Argungu transect									
Pedon AR1, Andaqueptic Fluvaquent															
A	0-35	4.7	4.5	7.05	3.11	0.60	0.61	0.48	11.85	39.54	27.69	95.9	28.7	5.28	0.2
AB_1	35-61	5.3	5.0	6.05	2.63	0.53	0.22	1.21	10.64	32.16	21.52	88.6	29.3	5.62	0.2
$2AB_2$	61-101	6.4	6.2	3.55	1.72	0.46	0.20	0.69	6.64	21.04	14.40	89.6	28.3	8.07	0.2
2Bwcg1	101-128	6.7	6.6	2.92	0.49	0.17	0.05	0.28	3.91	9.87	5.96	92.8	36.8	4.68	0.3
$2Bwcg_2$	128-157	7.2	7.0	3.22	1.53	0.48	0.10	0.30	5.63	13.60	7.97	94.7	39.2	9.00	0.5
$2BCg_1$	157-173	6.8	6.7	2.31	1.64	0.55	0.09	0.29	4.88	11.48	6.60	94.0	40.0	11.98	0.4
$2BCg_2$	173+	6.1	6.0	5.41	3.56	0.80	0.20	0.31	10.30	33.01	22.71	97.0	30.3	8.01	0.3
Pedon AR2; Andaqueptic Fluvaquent															
A	0-24	5.7	5.5	7.40	3.74	0.46	0.30	0.63	12.53	43.81	31.28	95.0	27.2	3.86	0.2
Bw_1	24-50	5.9	5.8	8.13	3.15	0.41	0.45	0.30	12.44	41.38	28.94	97.6	29.3	3.38	0.1
2Bw2	50-77	6.0	5.9	4.10	1.95	0.21	0.12	0.37	6.75	25.40	18.65	94.5	25.1	3.29	0.2
2BC1	77-110	6.2	6.0	2.56	1.40	0.20	0.10	0.22	4.48	9.56	5.08	95.1	44.6	4.69	0.2
2BC2	110-179	6.2	6.1	0.55	0.38	0.15	0.03	0.56	1.67	3.00	1.33	66.5	37.0	13.51	0.2
Pedon AR3; Tropaquent															
A	0-31	5.5	5.2	11.53	7.11	0.88	0.72	0.49	20.73	48.22	27.49	97.6	42.0	4.35	0.5
BA	31-58	5.7	5.5	13.78	8.19	1.06	0.56	0.55	24.14	53.21	29.07	97.7	44.3	4.49	0.5
Bw1	58-85	6.1	5.9	12.06	7.51	1.34	0.59	0.65	22.15	51.64	29.49	97.1	41.6	6.23	0.8
2Bwcg2	85-118	7.6	7.5	6.08	2.45	0.75	0.25	0.18	9.71	32.30	22.59	98.1	29.5	7.87	1.4
3Bwcg3	118-160	7.4	7.3	6.14	2.30	0.98	0.22	0.24	9.88	31.84	21.96	97.6	30.3	10.16	2.0
3BC	160-194	7.3	7.2	0.63	0.45	0.25	0.04	0.13	1.50	4.24	2.74	91.3	32.3	18.25	1.2
Pedon AR4;															
A	0-18	4.9	4.8	2.64	1.35	0.23	0.22	0.28	4.72	12.06	7.34	94.1	36.8	5.16	0.2
Bw	18-50	5.6	5.5	5.59	1.97	0.48	0.12	0.98	9.14	34.45	25.31	89.3	23.7	5.88	0.2
BC	50-85	5.3	5.2	1.42	0.50	0.23	0.11	1.04	3.30	7.92	4.62	68.5	28.5	10.18	0.1

Appendix D Continued

Pedon AR5;	Albaquic Paleudalf														
A	0-21	5.6	5.4	4.95	2.01	0.53	0.24	0.61	8.34	22.53	14.19	92.7	34.3	6.86	0.6
BA	21-40	6.9	6.7	8.75	2.60	1.03	0.03	0.63	13.04	35.84	22.80	95.2	34.6	8.30	0.8
B_{t1}	40-71	8.0	7.8	8.40	2.19	0.88	0.24	0.65	12.36	29.67	17.31	94.7	39.5	7.51	4.1
B_{t2}	71-110	7.2	6.8	5.16	1.49	0.50	0.22	0.32	7.69	21.00	13.31	95.8	35.1	6.78	1.2
BCg	110-140	6.5	6.1	0.66	0.33	0.17	0.04	0.18	1.38	3.61	2.23	86.9	33.2	14.17	0.7
2Cg	140-165	6.1	5.9	1.49	0.64	0.20	0.08	0.18	2.79	6.10	3.31	93.5	42.8	7.66	0.5
Pedon AR6;	Kanhaplic Haplustalf														
A	0-22	5.5	5.4	1.99	1.10	0.20	0.22	0.25	3.76	8.92	5.16	93.4	39.3	5.70	0.2
B_{t1}	22-41	5.9	5.7	8.63	3.36	0.34	0.29	0.17	12.79	36.44	23.65	98.7	34.6	2.69	0.3
B_{t2}	41-59	5.6	5.4	8.23	3.05	0.39	0.34	0.20	12.21	31.56	19.35	98.4	38.0	3.25	0.2
B_{t3}	59-88	5.3	5.2	5.71	2.39	0.32	0.15	0.32	8.89	26.00	17.11	96.4	33.0	3.73	0.2
BC	88-113	5.7	5.4	2.41	1.13	0.27	0.11	0.30	4.22	9.84	5.62	92.9	39.8	6.89	0.2
C	113-180+	6.6	6.4	0.46	0.03	0.22	0.06	0.28	1.05	2.62	1.57	73.3	29.4	28.57	0.2
				Lunda transect											
				Ca	Mg	Na	K	acidity	eCEC	ECEC	δCEC				
Pedon LD1;	Typic Pellustert														
A	0-18	6.1	5.9	17.92	8.30	0.95	0.91	0.32	28.40	68.59	40.19	98.9	40.9	3.38	0.4
AB	18-38	7.1	6.8	15.62	6.96	1.01	0.71	0.26	24.56	51.37	26.81	98.9	47.3	4.16	0.8
Bw1	38-57	7.1	6.8	19.76	7.61	1.79	0.96	0.68	30.80	73.54	42.74	97.8	40.9	5.94	1.6
Bw2	57-96	7.6	6.8	19.25	7.04	2.01	1.14	0.88	31.12	78.20	47.08	97.2	38.7	6.65	2.1
2BC	96-119	7.2	7.0	14.65	5.56	1.40	0.74	0.33	22.68	48.81	26.13	98.5	45.8	6.26	1.1
2C	119-162	7.6	7.3	8.58	2.25	0.60	0.29	0.29	12.01	31.43	19.42	97.6	37.3	5.12	0.9
Pedon LD2;	Typic Chromustert														
A	0-14	5.1	5.0	4.41	1.76	0.23	0.24	0.19	6.83	15.31	8.48	97.2	43.4	3.46	0.2
2BA	14-44	5.9	5.6	11.70	3.77	0.50	0.14	0.18	16.29	48.27	31.98	98.9	33.4	3.10	0.3
2Bw1	44-85	6.6	6.4	12.63	3.58	0.75	0.22	0.17	17.35	46.00	28.65	99.0	37.3	4.36	0.5
2Bw2	85-117	7.7	6.6	14.82	3.74	1.06	0.37	0.32	20.31	49.63	29.32	98.4	40.3	5.30	1.0
2BC	117-137	8.0	6.8	12.63	3.94	1.03	0.35	0.29	18.44	37.71	19.27	98.4	48.1	5.67	1.8
2C	137-181	8.1	6.9	7.64	2.26	0.80	0.29	0.54	11.45	24.08	12.63	95.3	45.3	7.33	2.0

Appendix D Continued

Pedon LD3; Oxic Ustropept

A	0-24	6.6	6.5	8.19	3.12	0.55	0.24	0.64	12.74	38.62	25.88	95.0	31.3	4.54	0.5
AB	24-44	7.2	7.0	15.20	4.85	1.88	0.30	0.55	22.78	53.16	30.38	97.6	41.8	8.46	0.5
2Bw1	44-56	8.0	7.7	20.15	6.31	2.71	0.34	0.58	30.09	69.05	38.96	98.1	42.7	9.18	0.8
2Bw2	56-85	8.3	8.0	18.75	7.26	3.71	0.40	0.78	30.90	71.28	40.38	97.5	42.2	12.32	4.0
2Bw3	85-115	7.7	7.5	21.85	7.71	4.46	0.44	0.74	35.20	72.01	36.81	97.9	47.8	12.94	1.5
3CB	115-160	7.7	7.5	17.12	4.62	2.27	0.25	0.67	24.93	49.80	24.87	97.3	48.7	9.36	1.5

Appendix E: Molar ratios of dithionite - extrabable Fe, Al, and Si.

Horizon	Depth(cm)	Molar Ratio					
		$\frac{Fe_2O_3(d)}{R_2O_3(d)}$	$\frac{Al_2O_3(d)}{R_2O_3(d)}$	$\frac{SiO_2(d)}{R_2O_3(d)}$	$\frac{Al_2O_3(d)}{Fe_2O_3(d)}$	$\frac{SiO_2(d)}{Fe_2O_3(d)}$	$\frac{SiO_2(d)}{Al_2O_3(d)}$
Makurdi transect							
Pedon MD1; Typic Ustifluvent							
Ap_1	0-24	1.52	0.18	1.36	0.12	0.90	7.60
A_2	24-59	1.49	0.24	2.91	9.16	1.97	12.31
$2BA_1$	59-87	1.36	0.43	2.47	0.31	1.82	5.77
$2BA_2$	87-120	1.42	0.35	1.86	0.24	1.32	5.39
2BC	120-168	1.51	0.21	2.23	0.14	1.49	10.85
Pedon MD2; Typic Udifluvent							
A	0-25	1.51	0.20	1.22	0.13	0.70	5.28
BA	25-60	1.56	0.12	1.16	0.07	0.74	9.80
Bw_1	60-97	1.58	0.09	0.69	0.05	0.44	7.91
Bw_2	97-130	1.58	0.10	1.30	0.06	0.83	13.27
BC	130-171	1.58	0.10	1.60	0.06	1.02	16.82
Pedon MD3; Andaqueptic Fluvaquent							
A	0-30	1.47	0.26	1.57	0.18	1.07	6.06
BA	30-45	1.55	0.14	0.81	0.09	0.52	5.72
$2Bw_1$	45-70	1.55	0.14	0.84	0.09	0.55	6.16
$2Bw_2$	70-113	1.55	0.14	1.02	0.09	0.66	7.30
2BCg	113-182	1.52	0.18	2.12	0.12	1.40	11.59

Appendix E (contd.)

Pedon MD4; Aquic Kandiustult

A	0-22	1.34	0.47	2.66	0.35	2.00	5.68
BA	22-64	1.41	0.36	2.13	0.26	1.52	5.90
Bwc_1	64-90	1.49	0.23	1.76	0.15	1.18	7.71
Bwc_2	90-128	1.55	0.13	1.47	0.09	5.23	10.98
BCg	128-185	1.57	0.10	1.59	0.07	1.02	15.10

Pedon MD5; Typic Kandiustalf

A	0-26	1.53	0.18	1.70	0.11	1.12	9.68
BA	26-59	1.57	0.11	1.85	0.07	1.19	16.73
Bt_1	59-80	1.60	0.06	1.91	0.04	1.20	31.84
Bt_2	80-124	1.60	0.06	1.14	0.04	0.71	18.54
C	124-185	1.37	0.05	1.19	0.03	0.75	24.73

<u>Gadza transect</u>

Pedon GZ1; Typic Tropaquept

A	0-21	0.87	1.20	8.52	1.38	9.84	7.10
BA	21-52	0.34	2.03	11.95	5.94	35.09	5.90
Bw	52-95	0.21	2.23	7.63	10.39	35.71	3.43
BC	95-129	0.09	2.47	8.45	25.63	89.89	3.50
Cg	129-192	1.17	0.73	4.20	0.62	3.60	5.76

Pedon GZ2; Typic Tropaquept

A_p	0-11	0.23	2.21	8.62	9.61	37.71	3.92
AB_1	11-32	0.10	2.41	9.52	23.53	93.45	3.97
AB_2	32-60	0.10	2.41	9.33	23.53	91.67	3.89
2BA	60-110	0.47	1.82	7.31	3.84	15.49	4.02

Appendix E (contd.)

Pedon GZ3; Typic Tropaquept

A	0-18	0.09	2.42	15.06	25.63	160.20	6.24
AB_1	18-55	0.03	2.51	13.33	70.60	376.47	5.32
AB_2	55-96	0.19	2.27	8.78	11.77	45.83	3.89
$2BA_1$	96-111	0.19	2.27	9.21	11.77	48.06	4.08
$2BA_2$	111-136	0.03	2.52	13.21	83.16	437.88	5.26
2BC	136-151	0.85	1.24	9.53	1.46	11.29	7.73
2C	151-192	0.21	2.23	7.84	10.39	36.71	3.53

Pedon GZ4; Aquic Quartzipsamment

Ap	0-20	0.85	1.23	6.11	1.44	7.19	4.99
AB_1	20-40	1.00	1.00	5.51	0.99	5.52	5.55
AB_2	40-60	0.99	1.02	5.06	1.04	5.16	4.96
BA	60-93	0.79	1.32	6.09	1.67	7.72	4.61
BC_1	93-169	0.70	1.46	6.22	2.08	8.87	4.26
BCrg2	169-192	1.04	0.93	5.23	0.89	5.06	5.65

Pedon GZ5; Typic Kandiustult

A	0-14	1.15	0.76	7.72	0.66	6.74	10.16
AB	14-37	1.29	0.55	2.26	0.43	1.76	4.13
BA	37-92	1.36	0.44	2.75	0.32	2.04	6.28
$2B_{t1}$	92-140	1.52	0.19	1.64	0.12	0.77	6.21
$2B_{t2}$	140-182	1.52	0.18	1.37	0.12	0.09	7.49
2C	182-207	1.52	0.17	1.82	0.11	1.20	10.41

Pedon GZ6; Typic Kandiustult

A	0-24	1.23	0.65	7.00	0.53	5.74	10.88
AB	24-59	1.35	0.46	1.78	0.34	1.33	3.88
$2B_{t1}$	59-97	1.56	0.12	0.45	0.08	0.29	3.69
2Bct1	97-160	1.56	0.12	1.13	0.08	0.73	9.30
2C	160-200	1.56	0.13	1.61	0.08	1.04	12.84

Dwam transect

Pedon DM1; Tropaquent

A	0-25	1.53	0.17	1.43	0.11	0.94	8.37
BAc	25-44	1.55	0.14	1.64	0.09	1.04	11.56
Bwc_1	44-72	1.53	0.17	1.84	0.11	1.21	10.71
Bwc_2	72-103	1.54	0.15	1.57	0.10	1.02	10.65
Bwc_3	103-135	1.53	0.18	2.04	0.12	1.35	11.62
C	135-179	1.46	0.28	3.28	0.19	2.26	11.79

Pedon DM2; Udic Chromustert

A	0-20	1.50	0.22	1.35	0.15	0.91	6.20
AB	20-42	1.50	0.22	1.56	0.14	1.04	7.16
Bw_1	42-74	1.51	0.20	1.65	0.14	1.10	8.10
Bw_2	74-109	1.52	0.19	1.82	0.13	1.20	9.52
BC	109-165	1.45	0.30	2.90	0.21	2.02	9.80

Appendix E (contd.)

Pedon DM3; Typic Kandiustalf

A	0-18	1.51	0.19	1.91	0.13	1.27	9.78
AB	18-43	1.46	0.28	2.35	0.19	1.62	8.46
B_{t1}	43-76	1.55	0.14	2.19	0.09	1.42	15.13
$2B_{t2}$	76-120	1.54	0.16	2.47	0.10	1.62	15.70
2C	120-160	1.56	0.13	2.10	0.08	1.36	16.72
R	160-175+	1.58	0.09	2.13	0.05	1.35	24.54

Argungu transect

Pedon AR1; Andaqueptic Fluvaquent

A	0-35	1.44	0.30	2.80	0.21	1.95	9.19
AB_1	35-61	1.52	0.19	2.28	0.12	1.51	12.29
AB_2	61-101	1.47	0.27	1.93	0.18	1.32	7.13
2Bwcg1	101-128	1.27	0.57	8.87	0.45	7.01	15.52
2Bwcg2	128-157	1.44	0.31	7.85	0.21	5.47	25.68
$2BCg_1$	157-173	1.53	0.18	1.81	0.12	1.19	10.20
$2BCg_2$	173+	1.43	0.33	7.00	0.23	4.94	21.05

Pedon AR2; Andaqueptic Fluvaquent

A	0-24	1.59	0.08	1.28	0.05	0.18	16.10
Bw_1	24-50	1,58	0.09	1.48	0.06	0.94	16.80
$2Bw_2$	50-77	1.51	0.20	2.78	0.13	1.85	13.95
$2BC_1$	77-110	1.50	0.21	3.32	0.14	2.22	15.87
$2BC_2$	110-179	1.18	0.72	11.54	0.61	9.85	16.09

Appendix E(contd.)

Pedon AR3; Tropaquent							
A	0-31	1.51	0.20	1.65	0.13	1.10	8.31
BA	31-58	1.54	0.15	2.48	0.10	-1.62	16.26
Bw_1	58-85	1.56	0.12	1.87	0.08	-1.21	15.30
$2Bwcg_2$	85-118	1.48	0.25	4.58	0.17	3.11	18.70
3Bwcg3	118-160	1.53	0.18	3.02	0.12	1.99	17.22
3BC	160-194	1.60	0.06	1.65	0.04	1.03	28.53
Pedon AR4; Typic Ustropept							
A	0-18	1.52	0.19	2.65	0.12	1.76	14.06
Bw	18-50	1.53	0.17	2.37	0.11	1.56	14.10
BC	50-85	1.24	0.62	5.94	0.50	4.80	9.62
C	85-170	1.15	0.77	11.86	0.67	10.38	15.52
Pedon AR5; Albaquic Paleudalf							
A	0-21	1.57	0.11	1.00	0.07	1.57	23.14
BA	21-40	1.59	0.08	1.67	0.05	1.05	21.71
B_{t1}	40-71	1.60	0.06	2.77	0.03	1.74	48.37
B_{t2}	71-110	1.56	0.12	3.27	0.08	2.11	27.09
BCg	110-140	1.46	0.28	4.76	0.19	3.28	17.11
Cg	140-165	1.62	0.03	2.56	0.02	1.59	89.65

Appendix E (contd.)

Pedon AR6; Kanhaplic Haplustalf

A	0-22	1.52	0.20	2.27	0.13	1.50	11.79
B_{t1}	22-41	1.58	0.09	2.16	0.05	1.37	24.93
B_{t2}	41-59	1.57	0.10	2.79	0.06	1.78	27.32
B_{t3}	59-88	1.55	0.13	1.79	0.08	1.16	13.52
BC	88-113	1.54	0.16	2.19	0.10	1.43	13.72
C	113-180+	1.21	0.66	13.61	0.55	11.27	20.57

<u>Lumda transect</u>

Pedon LD1; Typic Pellustert

A	0-18	1.39	0.39	2.29	0.28	1.66	5.89
AB	18-38	1.35	0.45	2.67	0.34	1.99	5.89
Bw_1	38-57	1.40	0.38	2.68	0.27	1.93	7.11
Bw_2	57-96	1.40	0.38	2.30	0.27	1.65	6.08
2BC	96-119	1.45	0.30	2.20	0.21	1.52	7.29
2C	119-162	1.37	0.42	5.37	0.31	3.95	12.79

Pedon LD2; Typic Chromustert

A	0-14	0.97	1.05	5.47	1.08	5.68	5.24
2BA	14-44	1.41	0.36	2.96	0.26	2.12	8.14
$2Bw_1$	44-85	1.40	0.38	2.51	0.27	1.81	6.66
$2Bw_2$	85-117	1.42	0.35	2.72	0.24	1.93	7.85
2BC	117-137	1.42	0.34	4.01	0.24	2.84	11.76
2C	137-181	1.42	0.34	4.19	0.24	2.97	12.29

Appendix E (contd.)

Pedon LD3; Oxic Ustropept

A	0-24	1.03	0.95	4.10	0.91	3.99	4.35
AB	24-44	0.88	1.19	5.05	1.36	5.78	4.25
$2Bw_1$	44-56	1.40	0.37	4.22	0.27	3.03	11.27
$2Bw_2$	56-85	1.45	0.29	2.76	0.20	1.91	9.53
$2Bw_3$	85-115	1.44	0.31	3.58	0.21	2.50	11.72
3CB	115-160	1.40	0.38	3.84	0.27	2.76	10.20

Appendix F: Total elemental analysis data.

Horizon	Depth	$Fe_2O_{3(t)}$	$SiO_{2(t)}$	$Al_2O_{3(t)}$	$MnO_{(t)}$	$MgO_{(t)}$	$CaO_{(t)}$	$K_2O_{(t)}$
		%						
Makurdi transect								
Pedon MD1; Typic Ustifluvent								
A_{p1}	0-24	6.10	64.38	17.83	0.09	0.69	0.86	0.10
A_2	24-59	5.93	64.16	19.66	0.06	0.58	0.61	0.08
$2BA_1$	58-87	3.86	60.74	18.04	0.05	0.64	0.67	0.08
$2BA_2$	87-120	3.86	58.30	21.61	0.07	0.66	0.72	0.07
2BC	120-168	4.83	61.12	19.37	0.04	0.53	0.53	0.05
Pedon MD2; Typic Udifluvent								
A	0-25	6.76	58.36	24.43	0.26	0.76	1.02	0.30
BA	25-60	10.02	57.65	21.96	0.08	0.88	0.98	0.11
Bw_1	60-97	9.14	60.01	18.90	0.08	0.77	0.78	0.13
Bw_2	97-130	7.07	59.43	17.51	0.04	0.94	1.10	0.32
BC	130-171	6.98	60.62	21.83	0.06	1.05	1.24	0.09
Pedon MD3; Andaqueptic Fluvaquent								
A	0-30	8.04	60.11	18.18	0.08	0.31	0.36	0.08
BA	30-45	8.38	58.68	18.46	0.12	0.08	0.21	0.06
$2Bw_1$	45-70	9.26	58.13	16.24	0.05	0.16	0.19	0.12
$2Bw_2$	70-113	9.85	61.06	20.08	0.06	0.18	0.24	0.14
2BCg	113-182	7.51	57.24	19.54	0.05	0.20	0.29	0.36

Appendix F(contd.)

Pedon MD4; Aquic Kandiustult

A	0-22	5.01	59.76	18.76	0.05	0.63	0.67	0.07
BA	22-64	4.86	62.04	22.38	0.11	0.04	0.54	0.09
Bwc_1	64-90	6.94	58.93	19.82	0.83	0.46	0.58	0.26
Bwc_2	90-128	7.37	59.51	16.19	0.92	0.07	0.61	0.11
BCg	128-185	7.68	57.87	18.33	0.07	0.55	0.63	0.20

Pedon MD5; Typic Kandiustalf

A	0-26	4.93	59.91	22.01	0.13	0.71	0.83	0.34
BA	26-59	6.17	60.26	18.91	0.06	0.08	0.46	0.31
Bt_1	59-80	7.66	61.44	20.73	0.08	0.42	0.46	0.26
Bt_2	80-124	5.82	62.03	22.28	0.04	0.26	0.27	0.14
C	124-185	8.04	61.84	21.06	0.03	0.30	0.36	0.19

Gadza transect

Pedon GZ1; Typic Tropaquept

A	0-21	3.52	66.36	21.00	0.15	0.45	0.88	0.17
BA	21-52	3.01	62.17	19.62	0.09	0.41	0.79	0.14
Bw	52-95	4.43	60.96	24.08	0.07	0.43	0.91	0.09
BC	95-129	4.69	56.08	22.15	0.06	0.50	1.34	0.09
Cg	129-192	2.88	60.00	18.28	0.13	0.46	0.98	0.18

Appendix F (contd.)

Pedon GZ2; Typic Tropaquept

A_p	0-11	4.53	68.72	24.55	0.17	0.41	0.48	0.08
AB_1	11-32	4.65	58.18	21.94	0.08	0.44	0.65	0.06
AB_2	32-60	4.34	60.23	24.06	0.09	0.50	0.93	0.11
2BA	60-110	2.05	57.54	20.33	0.14	0.55	1.27	0.16
2Cg	110-168	2.00	54.09	19.92	0.04	0.49	0.79	0.10

Pedon GZ3; Typic Tropaquept

A	0-18	4.89	62.36	24.50	0.11	0.42	0.53	0.18
AB_1	18-55	4.52	61.25	17.82	0.14	0.51	1.06	0.14
AB_2	55-96	3.03	63.70	23.57	0.18	0.53	1.39	0.23
$2BA_1$	96-111	3.41	64.01	15.19	0.21	0.45	0.49	0.25
$2BA_2$	111-136	3.67	57.82	19.94	0.08	0.32	0.59	0.12
2BC	136-151	3.03	70.34	15.53	0.13	0.64	1.26	0.15
2C	151-192	2.16	55.12	21.52	0.02	0.37	1.03	0.04

Pedon GZ4; Aquic Quartzipsamment

A_p	0-20	2.85	59.44	17.87	0.20	0.46	0.93	0.16
AB_1	20-40	3.17	55.83	19.02	0.16	0.41	0.34	0.13
AB_2	40-60	3.64	61.09	12.33	0.13	0.30	0.26	0.11
BA	60-93	3.27	58.27	20.02	0.08	0.09	0.18	0.08
BC_1	93-169	2.96	67.33	19.35	0.06	0.06	0.43	0.07
$BCrg_2$	169-192	4.02	68.46	15.64	0.04	0.39	0.57	0.09

Appendix F Contd.

Pedon GZ5; Typic Kandiustult

A	0–14	2.98	47.71	19.70	0.16	0.32	0.46	0.2[illegible]
AB	14–37	3.15	64.68	16.12	0.11	0.28	0.51	0.2[illegible]
BA	37–92	3.79	65.73	18.41	0.16	0.31	0.73	0.2[illegible]
$2B_{t1}$	92–140	6.20	69.08	17.79	0.09	0.10	0.39	0.1[illegible]
$2B_{t2}$	140–182	6.38	59.22	18.24	0.10	0.06	0.68	0.1[illegible]
2C	182–207	6.71	61.14	16.66	0.04	0.33	1.01	0.0[illegible]

Pedon GZ6; Typic Kandiustult

A	0–24	2.64	68.37	17.00	0.12	0.36	0.61	0.1[illegible]
AB	24–59	4.07	60.81	24.93	0.18	0.28	0.66	0.21
$2B_{t1}$	59–97	10.68	61.27	21.63	0.19	0.43	0.60	0.21
$2Bct_2$	97–160	9.81	68.16	19.71	0.04	0.08	0.74	0.2[illegible]
2C	160–200	9.63	58.41	22.12	0.06	0.11	0.85	0.1[illegible]

Dwam transect

Pedon DM1; Tropaquent

A	0–25	7.62	64.13	22.04	0.09	0.58	1.64	0.1[illegible]
BAc	25–44	7.45	60.75	21.63	0.52	0.45	1.03	0.07
Bwc_1	44–72	6.83	62.46	23.72	0.64	0.38	1.04	0.07
$2Bwc_2$	72–103	7.93	58.10	19.22	0.47	0.25	0.87	0.09
$2Bwc_3$	103–135	7.24	59.72	18.85	0.33	0.10	0.79	0.04
2C	135–179	6.11	63.35	20.06	0.08	0.08	0.13	0.03

Pedon DM2; Udic Chromustert

A	0–20	5.31	60.72	21.47	0.07	0.64	1.13	0.15
AB	20–42	4.24	59.68	22.61	0.04	0.68	1.26	0.12
Bw_1	42–74	3.93	59.04	2[illegible].22	0.05	0.70	1.08	0.12
Bw_2	74–109	3.80	58.55	23.06	0.02	0.43	1.17	0.20
BC	109–165	2.29	59.85	20.19	0.02	0.38	1.26	0.11

Pedon DM3; Typic Kandiustalf

A	0–18	6.40	63.52	21.74	0.08	0.06	0.64	0.0[illegible]
AB	18–43	5.62	64.26	18.33	0.07	0.08	0.13	0.04

Appendix F Contd.

B_{t1}	43-76	7.31	62.71	19.64	0.16	0.08	0.10	0.
$2B_{t2}$	76-120	6.16	61.08	18.09	0.35	0.12	0.25	0.
2C	120-160	7.95	60.32	17.31	0.29	0.13	0.73	0.
R	160-175+	7.62	58.69	19.58	0.24	0.22	0.76	0.

Argungu transect

Pedon AR1; Andaqueptic Fluvaquent

A	0-35	4.00	61.29	20.64	0.04	0.26	0.46	0.
AB_1	35-61	6.32	59.38	19.93	0.02	0.14	0.32	0.
$2AB_2$	61-101	4.57	60.41	19.98	0.03	0.09	0.14	0.
$2Bwcg_1$	101-128	3.82	63.70	17.10	0.45	0.03	0.09	0.
$2Bwcg_2$	128-157	3.01	64.92	16.85	0.68	0.07	0.16	0.
$2BCg_1$	157-173	6.00	58.81	18.63	0.05	0.08	0.10	0.
$2BCg_2$	175+	3.44	66.37	16.90	0.07	0.19	0.26	0.

Pedon AR2; Andaqueptic Fluvaquent

A	0-24	11.83	64.72	18.05	0.10	0.21	0.51	0.
Bw_1	24-50	11.04	65.30	20.16	0.05	0.23	0.54	0.
2Bw2	50-77	7.39	60.24	17.34	0.05	0.10	0.18	0.
$2BC_1$	77-110	8.65	59.98	17.65	0.03	0.06	0.13	0.
$2BC_2$	110-179	4.24	61.15	16.92	0.05	0.01	0.02	0.

Pedon AR3; Tropaquent

A	0-31	10.33	60.13	19.67	0.08	0.38	1.00	0.
BA	31-58	8.67	61.94	21.09	0.07	0.42	1.10	0.
Bw_1	58-85	8.19	57.08	17.83	0.04	0.43	0.98	0.
$2Bwcg_2$	85-118	5.04	59.26	18.24	0.32	0.08	0.32	0.
$3Bwcg_3$	118-160	5.66	56.98	16.68	0.21	0.09	0.46	0.
3BC	160-194	10.91	63.37	17.33	0.02	0.03	0.04	0.

Pedon AR 4; Typic Ustropept

A	0-18	7.06	62.09	18.35	0.08	0.09	0.09	0.
Bw	18-50	8.11	64.74	19.04	0.03	0.08	0.37	0.
BC	50-85	3.02	60.38	17.28	0.02	0.03	0.05	0.
C	85-170	2.69	59.91	19.01	0.02	0.04	0.04	0.

Appencis F Contd.

Pedon AR5; Albaquic Paleudalf

A	0–21	10.45	64.83	19.38	0.06	0.08	0.31	0.C
BA	21–40	10.03	65.04	16.86	0.04	0.11	0.36	0.C
B_{t1}	40–71	8.10	63.21	17.01	0.04	0.09	0.45	0.0
B_{t2}	71–110	6.37	63.27	18.16	0.03	0.09	0.32	0.0
BCg	110–140	3.84	61.52	18.24	0.02	0.02	0.02	0.0
2Cg	140–165	13.29	63.01	17.92	0.04	0.04	0.05	0.0

Pedon AR6; Kanhaplic Haplustalf

A	0–22	8.65	61.98	20.02	0.14	0.15	0.18	0.1
B_{t1}	22–41	13.37	60.24	19.63	0.10	0.21	0.44	0.1
B_{t2}	41–59	11.19	58.87	18.04	0.12	0.13	0.36	0.1
Bt_3	59–88	8.50	57.39	19.00	0.08	0.09	0.31	0.1
BC	88–113	8.02	60.64	17.82	0.03	0.04	0.05	0.0
C	113–180+	3.00	61.08	16.49	0.03	0.04	0.04	0.0

Lumda transect

Pedon LD1; Typic Pellustert

A	0–18	4.51	59.46	18.86	0.04	0.52	1.26	0.3
AB	18–38	3.63	58.60	23.51	0.02	0.28	1.01	0.2
BW_1	38–57	3.98	59.13	19.66	0.01	0.40	1.64	0.2
Bw_2	57–96	4.73	65.09	18.09	0.02	0.47	1.16	0.3
2BC	96–119	5.02	54.68	16.38	0.02	0.25	0.39	0.1
2C	119–162	2.31	60.06	18.75	0.01	0.06	0.05	0.0

Pedon LD2; Typic Chromustert

A	0–14	3.46	62.87	20.61	0.03	0.02	0.04	0.0
2BA	14–44	3.93	64.02	22.52	0.04	0.18	0.96	0.0
$2Bw_1$	44–85	4.10	60.73	21.00	0.02	0.16	0.98	0.0
$2Bw_2$	85–117	4.62	59.36	17.53	0.02	0.15	1.13	0.1
2BC	117–137	4.17	63.25	19.28	0.02	0.20	1.02	0.1
2C	137–181	3.35	63.68	16.33	0.01	0.09	0.09	0.0

Appendix F Contd.

Pedon LD3; Oxic Ustropept

A	0-24	3.26	65.34	22.97	0.07	0.08	0.09	0.05
AB	24-44	2.79	65.61	20.61	0.08	0.16	1.09	0.12
$2Bw_1$	44-56	3.06	66.82	21.38	0.05	0.23	1.60	0.14
$2Bw_2$	56-85	3.73	65.04	19.44	0.03	0.48	1.35	0.23
$2Bw_3$	85-115	3.29	66.93	17.27	0.04	0.48	1.66	0.26
3CB	115-160	3.98	66.77	17.63	0.01	0.16	1.18	0.09

Appendix G: Dithionite- and oxalate-extractable Fe, Al, and Si data.

Horizon	Depth (cm)	DCB extractable Fe_2O_3(d)	Al_2O_3(d)	SiO_2(d)	Oxalate extractable Fe_2O_3(o)	Al_2O_3(o)	SiO_2(o)	$\frac{Fe_2O_3(o)}{Fe_2O_3(d)}$	$\frac{Al_2O_3(o)}{Al_2O_3(d)}$
		%							
					Makurdi transect				
Pedon MD1; Typic Ustifluvent									
Ap1	0-24	5.06	0.38	1.70	1.94	0.31	0.82	0.38	0.81
A2	24-59	4.03	0.41	2.97	1.65	0.24	1.12	0.41	0.58
2BA1	59-87	1.89	0.38	1.29	0.23	0.33	0.96	0.42	0.87
2BA2	87-120	2.63	0.41	1.30	1.15	0.31	0.87	0.44	0.76
2BC	120-168	3.89	0.34	2.17	0.83	0.29	0.91	0.21	0.85
Pedon MD2; Typic Udifluvent									
A	0-25	6.75	0.57	1.77	1.29	0.75	0.93	0.19	1.31
BA	25-60	7.03	0.34	1.96	1.19	0.45	1.02	0.17	1.32
Bw1	60-97	7.32	0.26	1.21	1.55	0.31	0.81	0.21	1.19
Bw2	97-130	6.52	0.26	2.03	1.40	0.34	1.10	0.21	1.31
BC	130-171	4.92	0.19	1.88	1.18	0.76	0.94	0.24	4.00
Pedon MD3; Andaqueptic Fluvaquent									
A	0-30	4.72	0.53	1.65	1.71	0.92	0.85	0.36	1.73
BA	30-45	8.38	0.49	1.65	1.47	0.51	0.78	0.17	1.04
2Bw1	45-70	7.95	0.45	1.63	1.25	0.54	0.73	0.16	1.20
2BW2	70-113	5.09	0.34	1.46	1.06	0.63	0.69	0.18	1.85
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.39	1.26	0.17	1.03

Appendix G contd.

Pedon MD4; Aquic Kandiustult									
A	0-22	1.83	0.41	1.37	1.11	0.32	0.02	0.61	0.78
BA	22-64	2.32	0.38	1.32	0.91	0.27	0.79	0.39	0.71
Bwc_1	64-90	2.66	0.26	1.18	0.51	0.28	0.66	0.19	1.08
B_{wc2}	90-128	4.72	0.26	1.68	0.52	0.28	0.98	0.11	1.08
BCg	128-185	6.06	0.26	2.31	0.50	0.34	1.21	0.08	1.31
Pedon MD5; Typic Kandiustalf									
A	0-26	3.12	0.23	1.31	0.56	0.12	0.78	0.18	0.52
EA	26-59	4.20	0.19	1.87	0.68	0.09	0.95	0.16	0.47
B_{t1}	59-80	4.57	0.11	2.06	0.60	0.08	1.01	0.13	0.73
B_{t2}	80-124	4.48	0.11	1.20	0.61	0.04	0.63	0.14	0.36
C	124-185	5.72	0.11	1.60	0.65	0.05	0.65	0.11	0.45

<u>Gadga transect</u>

Pedon GZ1; Typic Tropaquept									
A	0-21	0.51	0.45	1.86	0.19	0.47	0.91	0.37	1.04
AB	21-52	0.14	0.55	1.84	0.10	0.52	0.85	0.71	0.98
Bw	52-95	0.08	0.53	1.07	0.10	0.44	0.67	1.25	0.63
BC	95-129	0.03	0.49	1.01	0.02	0.54	0.51	0.67	1.10
Cg	129-192	1.23	0.49	1.66	0.09	0.61	0.73	0.07	1.24
Pedon GZ2; Typic Tropaquept									
Ap	0-11	0.08	0.49	1.13	0.15	0.57	0.69	1.87	1.16
AB_1	11-32	0.03	0.45	1.05	0.04	0.32	0.57	1.33	0.71
AB_2	32-60	0.03	0.45	1.03	0.04	0.24	0.53	1.33	0.53
2BA	60-110	0.20	0.49	1.16	0.20	0.60	0.67	1.00	1.22
2Cg	110-168	0.03	0.49	1.03	0.06	0.79	0.51	2.00	1.61

Appendix G Contd.

Pedon GZ 3; Typic Tropaquept									
A	0-18	0.03	0.49	1.00	0.11	0.9	0.94	3.67	2.00
AB_1	18-55	0.01	0.45	1.41	0.05	0.92	0.78	5.00	2.04
AB_2	55-96	0.06	0.45	1.03	0.06	0.64	0.62	1.00	1.42
$2BA_1$	96-111	0.06	0.45	1.08	0.45	0.58	0.65	7.50	1.29
$2BA_2$	11-136	0.01	0.53	1.64	0.37	0.85	0.81	37.00	1.60
2BC	136-151	0.57	0.53	2.41	0.40	0.96	1.11	0.70	1.81
2C	151-192	0.08	0.53	1.10	0.18	1.20	0.73	2.25	2.26
Pedon GZ4; Aquic Quartzipsamment									
Ap	0-20	0.49	0.45	1.32	0.08	0.41	0.88	0.16	0.91
AB_1	20-40	0.71	0.45	1.47	0.12	0.45	0.91	0.17	1.00
AB_2	40-60	0.74	0.49	1.43	0.13	0.51	0.85	0.17	1.04
BA	60-93	0.46	0.49	1.33	0.19	0.62	0.73	0.41	1.26
BC_1	93-169	0.37	0.49	1.23	0.09	0.66	0.61	0.24	1.35
$BCrg_2$	169-192	0.86	0.49	1.63	0.05	0.97	0.82	0.06	1.98
Pedon GZ5; Typic Kandiustult									
A	0-14	0.97	0.41	2.45	0.04	0.31	1.14	0.04	0.76
AB	14-37	1.80	0.49	1.19	0.04	0.20	0.70	0.02	0.41
BA	37-92	2.71	0.50	[illegible].07	0.06	0.08	0.93	0.02	0.14
$2B_{t1}$	92-140	6.20	0.49	1.79	0.08	0.09	0.87	0.01	0.18
$2B_{t2}$	140-182	6.37	0.49	2.16	0.12	0.09	1.01	0.02	0.18
2C	182-207	6.69	0.49	3.00	0.16	0.06	1.12	0.02	0.12

Appendix G Contd.

Pedon GZ6; Typic Kandiustult									
A	0–24	1.34	0.45	2.88	0.14	0.07	1.09	0.10	0.15
AB	24–59	2.43	0.53	1.21	0.06	0.08	0.68	0.02	0.15
$2B_{t1}$	59–97	10.61	0.53	1.15	0.13	0.09	0.59	0.01	0.17
$2B_{ct2}$	97–160	9.81	0.49	2.68	0.35	0.04	1.04	0.03	0.08
2C	160–200	9.52	0.49	3.70	0.14	0.02	1.25	0.01	0.04
				Dwam transect					
Pedon DM1; Tropaquent									
A	0–25	5.72	0.41	2.02	0.49	0.46	1.43	0.08	1.12
BAc	25–44	5.12	0.30	2.04	0.40	0.74	1.38	0.08	2.47
Bwc_1	44–72	4.17	0.30	1.89	0.25	0.88	1.14	0,06	2.93
$2Bwc_2$	72–103	4.92	0.30	1.88	1.19	0.85	0.95	0.24	2.83
$2Bwc_3$	103–135	4.06	0.30	2.05	1.11	0.41	1.06	0.27	1.37
2C	135–179	2.46	0.30	2.08	0.12	0.37	1,55	0.05	1.23
Pedon DM2; Udic Chromustert									
A	0–20	4.83	0.45	1.64	0.36	0.25	0.97	0.07	0.55
AB	20–42	4.09	0.38	1.60	0.24	0.49	0.83	0.06	1.29
Bw_1	42–74	3.92	0.34	1.62	0.21	0.77	0.85	0.05	2.26
Bw_2	74–109	3.72	0.30	1.68	0.09	0.84	0.92	0.02	2.80
BC	109–165	2.29	0.30	1.73	0.01	1.36	1.03	NS	4.53

Appendix G Contd.

Pedon DM3; Typic Kanuiustalf									
A	0-18	4.97	0.41	2.36	0.11	0.98	1.80	0.02	2.39
AB	18-43	3.69	0.45	2.24	0.04	0.73	1.46	0.01	1.62
B_{t1}	43-76	5.00	0.30	2.67	0.02	0.56	1.93	NS	1.87
$2B_{t2}$	76-120	4.57	0.30	2.77	0.01	0.33	1.94	NS	1.10
2C	120-160	5.80	0.30	2.95	0.06	0.35	1.01	0.01	1.17
R	160-175+	6.55	0.23	3.32	0.07	0.19	1.14	0.01	0.83
Argungu transect									
Pedon AR1; Andaqueptic Fluvaquent									
A	0-35	3.63	0.49	2.65	0.36	0.36	1.00	0.10	0.73
AB_1	35-61	3.32	0.26	1.88	1.72	0.35	0.87	0.52	1.35
$2AB_2$	61-101	2.20	0.26	1.09	1.43	0.41	0.52	0.65	1.58
$2Bwcg_1$	101-128	0.80	0.23	2.10	1.10	0.63	0.51	1.37	2.74
$2BCg_2$	128-157	1.40	0.19	2.87	1.07	0.69	0.96	0.76	3.63
$2BCg_1$	157-173	4.03	0.30	1.80	1.11	0.38	0.43	0.27	1.43
$2BCg_2$	173+	1.74	0.26	3.22	1.17	0.52	1.19	0.67	2.00
Pedon AR2; Andaqueptic Fluvaquent									
A	0-24	11.81	0.38	3.60	1.31	0.29	1.24	0.11	0.76
Bw_1	24-50	9.52	0.34	3.36	1.55	0.34	1.17	0.16	1.00
$2B_{w2}$	50-77	4.03	0.34	2.79	1.19	0.32	0.95	0.29	0.94
$2BC_1$	77-110	3.37	0.30	2.80	1.10	0.46	0.99	0.33	1.53
$2BC_2$	110-179	0.77	0.30	2.84	1.10	0.49	1.08	1.43	1.63

Appendix G ontd.

Pedon AR3; Tropaquent									
A	0-31	6.29	0.53	2.59	0.10	0.56	0.98	0.01	1.06
BA	31-58	4.74	0.30	2.87	0.25	0.50	1.11	0.05	1.67
Bw1	58-85	4.57	0.23	2.07	0.59	0.66	0.86	0.13	2.87
$2Bwcg_2$	85-118	2.17	9.23	2.53	0.22	0.85	0.94	0.10	3.69
$3Bwcg_3$	118-160	3.12	0.23	2.33	0.16	0.74	0.88	0.05	3.22
3BC	160-194	9.95	0.23	3.86	0.27	0.91	1.28	0.03	3.96
Pedon AR4; Typic Ustropept									
A	0-18	5.15	0.41	3.39	0.10	0.35	1.20	0.02	0.85
Bw	18-50	5.89	0.41	3.44	0.16	0.43	1.17	0.03	1.05
BC	50-85	1.29	0.41	2.32	0.20	0.47	1.07	0.15	1.15
C	85-170	0.54	0.23	2.10	0.15	0.56	0.85	0.28	2.43
Pedon AR5; Albaquic Paleu alf									
A	0-21	9.46	0.41	5.58	1.05	0.33	1.29	0.11	0.80
BA	21-40	8.40	0.26	3.32	1.54	0.28	1.16	0.18	0.08
B_{t1}	40-71	4:80	0.11	3.13	1.25	0.32	0.97	0.26	2.91
B_{t2}	71-110	3.03	0.15	2.39	1.07	0.44	0.93	0.35	2.93
BCg	110-140	1.23	0.15	1.51	1.03	0.43	0.94	0.84	2.87
2Cg	140-165	13.29	0.15	7.91	1.1[illegible]	0.49	1.30	0.09	3.27
Pedon AR6; Kanhaplic Haplustalf									
A	0-22	6.03	0.49	3.40	0.14	0.16	1.08	0.02	0.33
Bt_1	22-41	12.81	0.45	6.60	0.20	0.12	1.25	0.02	0.27
B_{t2}	41-59	9.86	0.41	6.59	0.33	0.19	1.21	0.03	0.46

Appendix G Contd.

B_{t3}	59–88	7.52	0.41	3.26	0.31	0.23	1.02	0.04	0.56
BC	88–113	6.17	0.41	3.31	0.18	0.21	1.04	0.03	0.51
C	113–180+	0.86	0.30	3.63	0.12	0.37	1.18	0.14	1.23

<u>Lumda transect</u>

Pedon LD1; Typic Pellustert

A	0–18	2.51	0.45	1.56	0.14	0.42	1.09	0.05	0.93
AB	18–38	2.09	0.45	1.56	0.09	0.51	1.24	0.04	1.13
Bw_1	38–57	2.20	0.38	1.59	0.06	0.46	1.26	0.03	1.21
Bw_2	57–96	2.60	0.45	1.61	0.08	1.02	1.25	0.03	2.27
2BC	96–119	2.86	0.38	1.63	0.09	0.72	1.28	0.03	1.89
2C	119–162	1.17	0.23	1.73	0.05	0.84	1.36	0.04	3.65

Pedon LD2; Typic Chromustert

A	0–14	0.71	0.49	1.51	0.20	0.25	1.13	0.23	0.51
2BA	14–44	2.29	0.38	1.82	0.19	0.26	1.26	0.08	0.68
$2Bw_1$	44–85	2.20	0.38	1.49	0.13	0.34	0.97	0.06	0.89
$2Bw_2$	85–117	2.17	0.34	1.57	0.06	0.69	1.00	0.03	2.03
2BC	117–137	1.69	0.26	1.80	0.11	1.53	0.93	0.06	5.88
2C	137–181	1.69	0.26	1.88	0.10	2.01	1.12	0.06	7.73

Pedon LD3; Oxic Ustropept

A	0–24	0.89	0.52	1.33	0.08	0.43	1.06	0.09	0.83
AB	24–44	0.60	0.52	1.30	0.16	0.66	1.04	0.27	1.27
$2Bw_1$	44–56	1.11	0.19	1.26	0.12	1.26	0.91	0.11	6.63
$2Bw_2$	56–85	1.80	0.23	1.29	0.15	1.84	0.94	0.08	8.00
2Bw3	85–115	1.40	0.19	1.31	0.12	0.68	0.94	0.08	3.58
3Cr	115–160	1.74	0.30	1.80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Appendix H: Silt fraction mineralogy of selected horizons of the soils.

Horizon	Depth (cm)	Quartz	Feldspar	Vermi-culite	Kaoli-nite	Mica
		%				
			Makurdi transect			
Pedon MD1; Typic Ustifluvent						
Ap1	0-24	62.3	8.0	-	13.9	15.8
2BA1	59-87	65.5	5.8	-	11.6	17.1
2BC	120-168	69.0	-	-	10.8	7.8
Pedon MD2; Typic Udifluvent						
A	0-25	63.1	3.8	-	11.3	21.8
Bw1	60-97	62.9	4.6	-	11.6	20.9
BC	130-171	63.2	3.8	-	10.8	22.2
Pedon MD3; Andaqueptic Fluvaquent						
A	0-30	59.4	-	-	21.9	18.7
2Bw2	70-113	60.2	-	-	28.2	11.6
2BCg	113-182	58.8	2.1	-	21.0	18.1
Pedon MD4; Aquic Kandiustult						
A	0-22	62.5	-	-	20.9	16.6
Bwc1	64-90	57.9	4.0	-	22.3	15.8
BCg	128-185	53.0	-	-	19.6	27.4
Pedon MD5; Typic Kandiustalf						
A	0-26	53.4	9.5	-	18.4	18.7
Bt1	59-80	53.6	4.2	-	21.0	21.2
C	124-185	48.5	7.3	-	24.4	19.8
			Gadza transect			
Pedon GZ1; Typic Tropaquept						
A	0-21	64.5	-	-	19.6	15.9
Bw	52-95	68.3	-	-	14.8	16.9
Cg	129-192	68.7	-	-	20.7	10.6

Appendix H Contd.

Pedon GZ2; Typic Tropaquept

Ap	0-11	60.3	-	-	18.9	20.8
2BA	60-110	55.1	-	-	21.4	23.6
2Cg	110-168	52.0	3.4	-	22.9	21.3

Pedon GZ3; Typic Tropaquept

A	0-18	56.4	-	-	22.1	21.5
2BA	96-111	51.7	6.5	-	21.8	20.0
2C	151-192	53.8	6.8	-	18.9	20.5

Pedon GZ4; Aquic Quartzipsamment

Ap	0-20	56.5	-	-	23.6	17.9
BA	60-93	59.1	5.3	-	18.6	16.8
BCrg2	169-192	56.6	5.5	-	18.2	19.9

Pedon GZ5; Typic Kandiustult

A	0-14	43.1	9.9	-	26.2	20.8
2Bt1	92-140	50.2	8.6	-	24.9	16.3
2C	182-207	51.9	10.2	-	17.0	20.9

Pedon GZ6; Typic Kandiustult

A	0-24	37.8	11.8	-	37.8	12.6
2Bt1	59-97	47.0	7.5	-	25.0	20.5
2C	160-200	48.5	7.0	-	26.5	18.0

Dwam transect

Pedon DM1; Tropaquent

A	0-25	49.3	8.4	9.3	15.5	17.5
Bwc1	44-72	56.0	5.0	8.6	14.0	16.4
2C	135-179	51.4	7.9	8.8	12.7	19.2

Pedon DM2; Udic Chromustert

A	0-20	38.4	14.7	-	19.9	27.0
Bw1	42-74	31.6	17.2	-	18.1	33.1
BC	109-165	25.3	24.0	-	10.3	40.4

Pedon DM3; Typic Kandiustalf

Appendix H Contd.

Argungu transect

Pedon AR1; Andaqueptic Fluvaquent						
A	0-35	61.4	7.5	-	12.3	18.8
2AB2	61-101	61.8	3.0	-	12.0	23.2
2BCg1	157-173	64.0	1.4	-	10.8	23.8
Pedon AR2; Andaqueptic Fluvaquent						
A	0-24	60.7	5.6	-	20.1	13.6
2Bw2	50-77	59.8	5.8	-	16.7	17.7
2BC2	110-179	60.2	5.2	-	5.6	35.0
Pedon AR3; Tropaquent						
A	0-31	57.3	11.3	-	9.7	21.7
Bw1	58-85	59.6	9.0	-	-	31.4
3Bwcg3	118-160	61.6	8.1	-	-	30.4
Pedon AR4;						
A	0-18	64.6	-	-	14.9	20.5
BC	50-85	63.5	5.5	-	8.2	22.8
Pedon AR5; Albaquic Paleudalf						
A	0-21	56.5	-	4.2	16.4	22.9
Bt1	40-71	56.0	3.8	6.0	10.6	23.6
2Cg	140-165	56.3	-	3.5	8.0	30.2
Pedon AR6; Kanhaplic Haplustalf						
A	0-22	52.3	8.6	-	18.6	20.5
Bt1	41-59	54.1	9.1	-	19.0	17.8
C	113-180+	57.7	11.8	-	9.9	20.6

Lumda transect

Pedon LD1; Typic Pellustert						
A	0-18	35.9	11.1	8.0	24.8	20.2
Bw2	57-96	31.6	21.4	13.6	21.5	23.1
2C	119-162	29.3	16.2	15.0	14.1	25.4

Appendix H Contd.

Pedon LD2; Typic Chromustert

A	0-14	36.5	15.8	5.4	22.0	25.7
2Bw1	44-85	33.3	17.4	7.3	18.8	30.5
2C	137-181	28.6	22.0	6.8	7.5	41.9

Pedon LD3; Oxic Ustropept

A	0-24	53.2	-	9.5	21.8	15.5
2Bw2	56-85	49.6	8.4	16.0	14.8	11.2
3CB	115-160	51.7	13.4	4.6	5.4	24.9

Appendix I: Clay fraction (<0.002mm) mineral composition of representative samples of the pedons.

Depth (cm)	kaolinite	metahalloysite	hydrous mica	smectite	chlorite	vermiculite	feldspar	muscovite	quartz	hematite	goethi
	%										
Makurdi transect											
Pedon MD1; Typic Ustifluvent											
0-24	74.6	12.9	-	-	-	-	6.8	-	5.7	-	-
59-87	71.7	16.7	8.8	-	-	-	-	-	2.8	-	-
120-168	59.9	18.0	8.5	-	-	-	5.9	4.0	4.7	-	-
Pedon MD2; Typic Udifluvent											
0-25	68.2	13.0	13.2	-	-	-	-	1.5	4.1	-	-
60-97	68.1	15.1	16.8	-	-	-	-	-	-	-	-
130-171	66.3	19.3	14.4	-	-	-	-	-	-	-	-
Pedon MD3; Andaqueptic Fluvaquent											
0-30	60.3	15.6	14.5	-	5.9	-	-	3.7	-	-	-
70-113	61.7	10.1	12.6	14.3	-	-	-	1.3	-	-	-
113-182	52.0	8.8	10.2	21.4	-	-	3.0	4.6	-	-	-
Pedon MD4; Aquic Kandiustult											
0-22	61.2	16.1	16.0	-	-	-	4.2	2.5	-	-	-
64-90	63.6	15.5	13.4	-	-	-	4.2	4.4	-	-	-
128-185	61.0	12.4	12.1	-	-	-	6.5	8.0	-	-	-
Pedon MD5; Typic Kandiustalf											
0-26	62.9	20.4	16.7	-	-	-	-	-	-	-	-
59-80	58.3	8.8	4.9	-	-	-	-	-	-	16.4	11.
124-185	59.8	4.9	3.0	-	-	-	3.8	-	-	15.8	14.
Gadza transect											
Pedon GZ1; Typic Tropaquept											
0-21	70.0	8.9	7.4	-	-	-	7.3	-	6.4	-	-
52-95	71.2	12.0	8.1	-	-	-	4.2	-	4.5	-	-
129-192	62.1	17.5	11.7	-	-	-	3.7	-	5.0	-	-

Appendix I Contd.

Pedon GZ2; Typic Tropaquept											
0-11	64.0	12.0	8.3	-	-	-	6.2	5.4	4.1	-	
60-110	68.3	16.2	9.5	-	-	-	1.6	-	4.4	-	-
110-168	65.6	20.1	11.0	-	-	-	-	3.3	-	-	-
Pedon GZ3; Typic Tropaquept											
0-18	59.9	19.4	8.0	-	-	-	4.6	3.1	5.0	-	-
99-111	60.1	21.1	14.2	-	-	-	2.0	2.6	-	-	-
151-192	62.4	20.3	8.2	-	-	-	-	2.4	6.7	-	-
Pedon GZ4; Aquic Quartzipsamment											
0-20	61.0	12.3	11.1	-	-	-	5.3	-	8.3	-	
60-93	61.3	18.2	10.2	-	-	-	2.4	-	7.9	-	
162-192	61.5	21.0	9.3	-	-	-	-	-	8.2	-	
Pedon GZ5; Typic Kandiustult											
0-14	54.5	18.2	17.5	-	-	-	-	-	9.8	-	
92-140	49.0	15.0	10.9	-	-	-	-	-	5.5	16.7	[illegible]
182-207	39.2	10.4	19.4	-	-	-	-	-	8.5	11.9	10
Pedon GZ6; Typic Kandiustult											
0-24	57.8	20.9	14.5	-	-	-	-	-	6.8	-	
59-97	46.3	11.1	5.3	-	-	-	-	-	7.6	19.4	10
160-120	43.2	9.4	7.5	-	-	-	-	-	11.8	14.6	13
Dwam transect											
Pedon DMI; Tropaquept											
0-25	49.4	-	14.1	-	-	19.6	10.7	6.2	-	-	-
44-72	47.5	-	16.0	-	-	18.8	11.3	6.4	-	-	-
135-179	50.9	-	11.4	-	-	20.3	11.2	6.2	-	-	-
Pedon DM2; Udic Chromustert											
0-20	17.3	-	1.8	35.2	23.6	-	10.9	3.2	-	-	-
42-74	18.9	-	2.3	30.9	19.4	-	16.7	3.8	-	-	-
109-165	19.1	-	3.9	34.3	19.3	-	17.4	6.0	-	-	-
Pedon DM3; Typic Kandiustalf											
0-18	64.6	-	9.3	-	-	-	10.7	7.3	8.1	-	-
76-120	63.5	-	10.5	-	-	-	10.0	6.1	7.9	-	2
[illegible]	[illegible]	-	16.3	-	-	-	18.5	-	-	-	-

Appendix I -Contd.

Argungu transect

Pedon AR1; Andaqueptic Fluvaquent											
0-35	60.8	9.1	8.3	-	-	-	13.8	-	8.0	-	
61-101	61.0	11.9	8.5	-	-	-	11.3	-	7.3	-	
157-173	56.1	19.3	6.2	-	-	-	10.4	-	8.0	-	
Pedon AR2; Andaqueptic Fluvaquent											
0-24	66.6	9.5	11.8	-	-	-	12.2	-	-	-	
50-77	68.0	9.2	5.5	-	-	-	15.3	2.0	-	-	
110-179	57.4	13.2	10.1	-	-	-	19.3	-	-	-	
Pedon AR3; Tropaquent											
0-31	69.3	-	11.4	-	-	-	16.1	3.2	-	-	
58-85	65.1	5.0	9.8	-	-	-	20.1	-	-	-	
118-160	66.0	-	18.3	-	-	-	12.2	3.5	-	-	
Pedon AR4; Typic Ustropept											
0-18	61.1	7.2	9.5	-	-	-	12.0	-	10.2	-	
50-85	59.3	10.0	8.3	-	-	-	11.1	-	11.3	-	
Pedon AR5; Albaquic Paleustalf											
0-21	56.3	-	1.2	-	-	14.4	13.0	4.0	11.1	-	
40-71	29.1	1.6	1.4	22.2	-	13.5	27.4	1.1	3.0	-	
140-165	28.6	1.0	2.6	28.4	-	-	27.9	1.2	3.4	-	[illegible]
Pedon AR6; Kanhaplic Haplustalf											
0-22	61.7	11.3	6.4	-	-	-	18.3	2.3	-	-	
41-59	48.5	6.9	7.5	-	-	-	18.0	1.4	3.6	-	[illegible]
113-180+	39.6	15.9	4.7	-	-	-	17.3	-	1.0	7.0	[illegible]

Lunda transect

Pedon LD1; Typic Pellustert											
0-18	16.8	-	1.5	34.6	22.4	-	19.7	5.0	-	-	
57-96	16.0	-	2.3	41.2	20.1	-	18.0	2.4	-	-	
119-162	21.2	-	3.9	30.1	24.4	-	14.3	2.0	4.1	-	
Pedon LD2; Typic Chromustert											
0-14	13.9	-	-	36.1	28.3	-	15.5	6.2	-	-	
[illegible]	[illegible]	2.0	-	37.3	26.1	-	13.1	3.2	-	-	

Appendix I Contd.

Pedon LD3; Oxic Ustropept

0-24	22.7	-	17.2	-	20.3	20.1	6.3	3.0	10.4	-
56-85	20.9	-	17.0	-	19.9	22.5	2.2	4.2	13.3	-
115-160	20.6	3.0	18.4	-	15.0	21.4	3.3	3.1	14.2	-